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SNOW AND ICE DETECTION AND WARNING SYSTEMS

August 1975
Final Report

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16. Abstract

This report summarizes the activity of a 2-year program to evaluate commercially available ice and snow detection and warning systems. The objectives were to select and operationally evaluate a number of promising detector systems and to prepare a data base of motorist behavior in adverse conditions for use in a motorist warning system study to be conducted during the second year of the study. Three detector systems were selected for evaluation. A bridge in the High Sierra Mountains near Truckee, California, was selected for the test site and fully instrumented with the detectors, as well as speed and weather measurement stations. A computerized, fully automatic data acquisition system was used to provide 24-hour-per-day recording of all sensor and detector information. Three optimally placed speed traps provided an approach speed profile for each of some 50,000 vehicles, automatically classified as car or truck that approached the bridge. Data recordings were made across a wide spectrum of environmental conditions. The performance of the ice/warning system. Although motorist behavior was found to be significantly altered by varying weather conditions, the manually operated motorist warning system also produced significant alterations in behavior.

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TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	1
2.0	SUMMARY	4
2.1	First Year Activities	4
2.2	Second Year Activities	6
3.0	CONCLUSIONS AND RECOMMENDATIONS	10
4.0	PHASE I - FIRST YEAR OF TESTING	13
4.1	Detector Requirements	13
4.2	Detectors Screened	15
4.3	Final Detector Selection	17
4.4	Site Selection	19
4.4.1	Site Requirements	19
4.4.2	Selection Process	21
4.4.3	Selected Candidate	22
4.5	Data Acquisition System	31
4.6	Site Configuration	33
4.6.1	Instrumentation/Observation Trailer	33
4.6.2	Ice and Snow Detectors	39
4.6.3	Traffic Measurement Stations	46
4.7	Site Operation	50
4.7.1	Observer Duties	51
4.7.2	Automatic Data System	52
4.8	Weather Conditions	55
4.9	Detector Performance	56
4.10	Traffic Performance	60
4.10.1	Two Snow Events	60
4.10.2	Other Speed Statistics	63
5.0	PHASE II - SECOND YEAR OF TESTING	69
5.1	Data Storage Program and Summer Testing of Sensor Systems	69

TABLE OF CONTENTS
(continued)

Section	Title	Page
5.1.1	Data Transfer and Storage Program	70
5.1.2	Sensor Laboratory Testing Program	72
5.1.2.1	System Modifications	72
5.1.2.2	System Testing	73
5.2	Restart of Winter Testing	74
5.2.1	Nova Programming Modifications	75
5.2.2	Speed Trap Calibration	76
5.3	Motorist Warning System	77
5.3.1	Sign Selection and Location	77
5.3.2	Motorist Warning System Control	83
5.4	Motorist Warning System Test	88
5.4.1	Criteria for Manual Motorist Warning Sign Operation	88
5.4.2	Hazardous Bridge Events	89
5.4.3	Snow and Ice Sensor Performance	92
5.4.3.1	Holley System Performance	97
5.4.3.2	Cytronics System Performance	98
5.4.3.3	SSI System Performance	99
5.4.4	Motorist Warning System Evaluation	104
5.4.4.1	Prosser Creek Traffic	107
5.4.4.2	Motorist Warning Experiment	110
5.4.4.3	Motorist Warning Experiment Results	111
5.4.4.4	Key Summary Results	114
	APPENDIX A HAZARD WARNING SYSTEM REQUIREMENTS	116
1.0	GUIDELINES TO SYSTEM DESIGN	117
2.0	SYSTEM PERFORMANCE REQUIREMENTS	118
3.0	ALTERNATIVE SENSOR ACTIVATED WARNING SYSTEMS	119

TABLE OF CONTENTS
(continued)

Section	Title	Page
	APPENDIX B SENSOR SYSTEM CALIBRATION TEST METHODOLOGY AND RESULTS	121
	APPENDIX C SPEED DATA ANALYSES AND RESULTS	133
	REFERENCES	161

LIST OF FIGURES

Figure No.	Title	Page
1	Candidate Bridge Sites	24
2	Prosser Creek Bridge	27
3	Road Geometry at Prosser Creek Bridge	28
4	Motorists' View of Test Section	29
5	Ice and Snow Dection and Warning System Data Acquisition System	32
6	Overall Test Site Configuration	34
7	Prosser Creek Bridge	35
8	Instrumentation/Observation Trailer	36
9	Floor Plan Instrumentation/Observation Trailer	37
10	Data Acquisition System Console	38
11	Instrumentation Trailer with View of Bridge Deck	40
12	Ice Detector Controller on Bridge Abutment	41
13	Ice and Snow Detector Controllers	42
14	Holley Humidity/Air Temperature Sensor	43
15	Bridge Deck Sensor Installation	44
16	Bridge Deck Sensor Head Array	45
17	SSI Bridge Deck Sensors	47
18	Holley Bridge Deck Sensors	47
19	Cytronics Bridge Deck Sensors	47
20	Traffic Measurement Stations	49
21	Illustrative Computer Printout	53
22	Vehicle Speeds Through New Years Eve Storm	62
23	Mean Speeds Spanning February 28 Storm	64
24	MBA's Terminal Facility CDC MARC II	71
25	Bridge Warning Sign	79
26	Advance Warning Sign	79
27	Motorist Warning Sign Location	80

LIST OF FIGURES
(continued)

Figure No.	Title	Page
28	Potential Skidding Hazard--Southbound View	82
29	Potential Skidding Hazard--Northbound View	82
30	Roadway View--Speed Trap No. 1	84
31	Roadway View--Advance Warning Sign	84
32	Roadway View--1000 Feet North of Bridge	85
33	Roadway View--800 Feet North of Bridge	85
34	600 Feet North of Bridge	86
35	Driver View at Speed Trap No. 2	86
36	Bridge Warning Sign	87
37	Driver View--Center of Bridge	87
38	Hazardous Bridge Condition	93
39	Hazardous Bridge Condition	93
40	Marginal Bridge Hazard Condition	94
41	Roadway Under Roadlight Illumination--Black Ice Condition	95
42	Bridge Warning Sign--Black Ice Condition	95
43	Bridge Surface View--Black Ice Condition	96
44	Bridge and South Approach--Black Ice Condition	96
45	SSI No. 1 False Alarm Data	101
46	SSI False Alarm Data	102
47	Prosser Creek Bridge Traffic Speed	106
B-1	SSI Sensor Sensitivity Tests	123
B-2	Stovepipe Air Temperature Thermistor Test	127
B-3	Sensor 1--Unheated Conductivity Tests	128
B-4		130
B-5	Linearity of Unheated Deck Sense vs. Temperature	131
C-1	Initial Trap 1 Truck Speed Distribution (Daylight Hours)	142
C-2	Initial Trap 1 Truck Speed Distribution (Night)	143

LIST OF FIGURES
(continued)

Figure No.	Title	Page
C-3	Initial Trap 1 Car Speed Distribution (Daylight Hours)	144
C-4	Initial Trap 1 Car Speed Distribution (Night)	145
C-5	Mean Trap 2 Speeds (Daylight Hours)	147
C-6	Mean Speed Change Between Trap 1 and Trap 2 (Daylight Hours)	149
C-7	Mean Trap 3 Speeds (Daylight Hours)	150
C-8	Mean Speed Change Between Trap 2 and Trap 3 (Daylight Hours)	151
C-9	Percentage of Vehicles Attaining Minimum Speed at Trap 2	152
C-10	Percent of Cars Achieving Minimum Speed at Trap 2	153
C-11	Mean Trap 2 Speeds (Night)	155
C-12	Mean Speed Change Between Trap 1 and Trap 2 (Night)	156
C-13	Mean Trap 3 Speeds (Night)	157
C-14	Mean Speed Change Between Trap 2 and Trap 3	158

LIST OF TABLES

Table No.	Title	Page
1	Candidate Bridge Sites	23
2	Weather Summary	26
3	National Weather Service Station Data	57
4	Speed Statistics, Vehicles	65
5	Vehicle Speed Statistics, April 1974	67
6	Motorist Warning Sign Operation Matrix	90
7	Hazardous Bridge Events, Motorist Warning System Test	91
8	False Alarm Analyses Based on Alternative SSI No. 1 Driven Motorist Warning Systems	103
9	SSI No. 1 Alarms Overlapping Icy Bridge Condition Events	105
10	Summary Speed Data	109
B-1	Controller Calibration	124
B-2	SSI Controller Monitor Point Voltages	125
C-1	Composite Monthly Speed Data--December 1973	134
C-2	Composite Monthly Speed Data--January 1974	135
C-3	Composite Monthly Speed Data--February 1974	136
C-4	Composite Monthly Speed Data--March 1974	137
C-5	Composite Monthly Speed Data--April 1974	138
C-6	1974 Base Data Vehicle Speed Analysis	139
C-7	1975 Motorist Warning Systems Tests, Vehicle Speed Analysis	140

1.0 INTRODUCTION

It has long been known that many accidents on the nation's highways occur as a result of motorists encountering situations which they had not anticipated. In these cases, the driver must react quickly and correctly to avoid being involved in or causing an accident. These situations demand driving skills and perception and reaction time that unfortunately many of the nation's motorists do not possess.

In recognition of this problem, State and Federal agencies for years have endeavored to alert the motorist to an impending hazard through use of signs, warning lights and various delineation techniques. To a large extent, these methods have been effective, where the warning given does not conflict with the driver's perception of the general conditions. An example would be a motorist driving in a mountainous area and encountering a sign warning of a particularly severe curve with a recommended reduction in speed. In this situation, because of his perception of the terrain, he is not surprised that such a curve exists and, in all probability, will respond accordingly.

Unlike that situation, there are certain environmental conditions which produce hazards that occur only intermittently. Two examples of such conditions are patchy fog and preferential icing of bridge decks. One of the most widespread techniques used to warn motorists of these situations is the use of static signs, stating the possibility that the hazard exists, e.g., "Bridge Freezes Before Roadway." Occasionally, the signs are active and are turned on by a passing Highway Patrolman or a maintenance crew.

Static warning signs alerting the motorist of an intermittent hazard suffer in effectiveness. This is primarily due to the fact that the hazard they describe occurs infrequently. A driver is not prone to respond to a "Frosty Bridge" sign on a hot summer afternoon. These signs communicate little in the way of timely information and may well produce a negative impact on the motorist.

There is very little highway maintenance personnel can do to eliminate fog, so they must resort to signing only. On the other hand, deicing chemicals can significantly reduce the frequency of preferentially frozen bridges. Unfortunately, with this means of making the bridge safer comes a responsibility in the event it is unsafe. States have been sued for accidents on slippery bridges which had not yet been treated for that particular occurrence.

To reduce the number of accidents related to preferential icing, many states have instituted the policy of frequent and routine treatment of the bridge deck. However, there are two problems associated with this policy. The first is that there is a limit to the effectiveness of deicing chemicals. Preferential icing can occur even when the bridge has been adequately treated if the temperatures are low enough. Secondly, the chemicals have an adverse effect on the bridge deck itself as well as the surrounding environment.

The first problem can only be handled by warning the motorist when the situation arises. The second requires that the bridge be treated as infrequently as possible. This requires an ability to predict an occurrence accurately and then to apply treatment. Since weather prediction tends to be somewhat unreliable, especially on a local basis, maintenance crews are prone to take the conservative approach and treat the bridges more often than absolutely necessary. The extra treatments are expensive in both labor and materials, and also in the deleterious side effects.

Over the years, industry both here and abroad became aware of these problems; and a number of ice and snow detection and prediction systems began to appear on the market. Many of these were and still are in a developmental stage with little or no proven operational reliability. As literature began to appear on these devices a number of states purchased devices on an individual evaluation basis. However, there was no comprehensive evaluation of the entire spectrum available. There was also a general lack of coordination among the researching agencies.

The Federal Highway Administration recognized that this uncoordinated approach could lead to duplication of effort, incorrect conclusions and inefficient use of State and Federal funds. This prompted the first of two studies to be undertaken to alleviate this problem. The program was entitled, "An Ice and Snow Detection and Warning System Feasibility Study," conducted by Midwest Research Institute under Contract No. FH-11-7428 in 1970 and 1971.

This study revealed that many of the systems were in a developmental state and did not possess operational reliability. One system, the Econolite, did perform with a reasonable degree of reliability. Unfortunately, this reliability was estimated using relatively few events. The device could not, however, detect frost. The study included the recommendation that further field evaluations and data analysis be performed, since cost benefit studies indicated that a reliable system could be cost effective to users.

As a result of that recommendation and the arrival of several new devices on the market, it was decided that a re-evaluation of ice detectors was in order. In July 1973, MBAssociates was awarded Contract No. DOT-FH-11-8127, to continue the evaluation of ice and snow detection systems and then to demonstrate their utility in conjunction with a motorist warning system. Of particular interest was the selection of a test site which would provide a large number of snow, ice and frost events so that system reliability would be proven with a high degree of confidence.

This report describes the activities undertaken during the two-year period. The primary activities during the first year were detector system selection, test site selection and, finally, the field evaluation of the systems. Second year activities included a summer laboratory testing program, a second sensor field evaluation, development, implementation analysis of a motorist warning system, and an evaluation of snow and ice sensor performance.

2.0 SUMMARY

This report describes the activities of a two-year study to evaluate ice and snow detection and motorist warning systems.

2.1 First Year Activities

The activities during the first year consisted of the selection of the most promising detector system candidates, the selection and preparation of an appropriate test location, the development of a data acquisition system and finally the conduct of the field evaluation during the 1973/1974 winter season. The data gathered during the first year of testing served as a basis for the laboratory testing which preceded the 1974/1975 field tests during winter months.

Detection system selection began with an extensive review of literature describing the wide variety of systems commercially available. Those State highway departments which had experience with certain of the detectors were contacted. A number of detector manufacturers were asked for price and availability information on their systems.

Based on the information collected, five ice and snow detection systems were selected for evaluation. The selected systems were the Holley Highway Ice Condition System; the Cytronics Ice, Snow and Frost Detection System; the Econolite Ice-Moisture Detector; the Surface Systems, Inc. Surface Condition Analyzer; and a system manufactured by Honeywell, Inc.

These five devices were based upon four different principles of operation: conductance, capacitance, spectral temperature, and latent heat of fusion.

Unfortunately, there were difficulties encountered in procuring devices from Econolite and Honeywell. Econolite was no longer manufacturing their device, but there was a possibility that devices would be available for inclusion in the evaluation. This did not materialize. The Honeywell device was found to be in development and the unit price was found to be excessively high and beyond the funds available.

Thus, two of each of the remaining three types were purchased for evaluation.

A test site was selected after virtually all bridges in California's Severe Environment Area were screened. The screening process involved such factors as altitude, traffic volume, approach and departure geometry, bridge length and local weather history. The surviving candidates were then inspected by the MBA staff before final selection was made.

The bridge eventually selected was one located in the High Sierras near Truckee, California, at 5700 feet elevation. That area is known for its particularly severe winter weather.

The data acquisition system selected for the task was based upon a Data General Corporation Nova 1210 minicomputer. The computer (through its auxiliary interface equipment) received, processed and recorded data from the six detectors on the bridge; eight types of weather and environmental data; and speed data from three stations approaching the bridge. The output was recorded on teletype paper in man-readable form and concurrently on paper punch tape. The system was designed for automatic 24-hour-a-day operation. Detailed documentation of the Nova 1210 programming is contained in Volume II of the project report.

The equipment was moved to the site and installed in November 1973. Data collection began in early December and continued through April 1974. During this period, the site was manned for four hours per day, seven days a week. The primary duty of the observer was to personally inspect and record the condition of the bridge deck.

During the test period, vehicle speeds were measured at three separate locations for each of over 35,000 vehicles under a wide variety of environmental conditions. The conditions include fair weather, day and night, snow storms with and without chain controls, and preferentially frosted bridge deck. This data provided an excellent basis of comparison for the motorist warning study completed in the winter of 1974-1975.

The actual weather conditions at the test site during the period were excellent for both the traffic study as well as the detector evaluation. From November through April, snow fell on 59 days and chain controls were in effect at the site on 38 of these days. Over 210 inches of snow fell during the period.

The results of the first year ice and snow detector evaluation were most disappointing. Throughout the period the devices experienced both electrical and mechanical failures, required modification, recalibration and adjustment. Constant liaison was maintained with the manufacturers during this period. All of the devices were operational at the beginning of April and were left unadjusted throughout the month. Only one unit, a Holley, showed reasonable performance. The others either failed completely or performed erratically.

Based upon these results, it was concluded that none of the detectors tested was sufficiently reliable or accurate to operate a motorist warning system in their current state of development. It was therefore recommended that a limited amount of laboratory research be performed during the summer in an attempt to upgrade them.

2.2 Second Year Activities

The second year of activities initiated with a summer laboratory test program on the three sensor systems. This program was aimed at correcting several deficiencies noted during the first year of winter testing in the Sierra test site. Another purpose of the test program was to search for particular anomalies in the sensor calibration which might provide additional information relative to inconsistencies observed in the first year of field testing.

Another task during the summer months of 1974 was the transferring of the data gathered by the Nova 1210 processor into a form accessible by another off-line computer system. This transfer of information would then allow for computer data analysis relative to any information collected at the field test site. The field test information

contained on the eight-channel paper tape rolls was transferred onto magnetic tape for analysis by Control Data Corporation's 6600 computer system. The major portion of this effort required the writing of a computer program to efficiently store this information so that post-analysis program would not require excessive access time.

Following the summer activities, MBA personnel returned to the Prosser Creek test site in mid-October 1974. Reinstallation of the equipment within the instrumentation trailer and under the bridge required approximately two weeks. During the latter portion of this period, all deck-mounted sensor heads were removed from the bridge. For the removal, calibration and reinstallation of the sensor heads, MBA field personnel were joined by representatives from both Cytronics and Surface Systems, Inc. New replacement sensor heads were used on both SSI systems and one Holley system. The Prosser Creek test site was restarted on 1 November 1974.

The "black road" policy of snow removal personnel in this region of the Sierras means that snow removal equipment will plow roadway snow and ice accumulation right down to the roadway surface. In the fear that a snow plow might inadvertently pluck one of these sensors from the bridge deck, it was required that the sensor heads be slightly depressed below the road surface. Such installation practice causes the areas above the sensor heads to be water collectors and can produce actual icy alarms on the sensor while the remainder of the bridge deck may be dry.

During the second winter of testing there were several computer failures which resulted in a total of three weeks of data loss. Additional problems with the snow and ice sensors delayed the start of the motorist warning system test until March 1975.

As opposed to the Holley system which had looked reliable during April 1974, it was the SSI units which appeared to be functioning better during the second year of testing. Due to probable interaction between vehicle car chains and the SSI heads, these sensor

heads were driven deeper into the road bed where they became major water collectors. Over the two test periods, the three system types had demonstrated a tendency to false alarm (go to an icy condition) even though the road, bridge and sensor head were dry and bridge deck temperature was 50 degrees F or higher. Although some false alarms are obvious from other instrumentation, it is difficult to determine when the sensor alarm was valid due to water collection over the sensor head while the bridge deck itself was dry. Compounding this problem was the fact that the epoxy material of the SSI head might well be colder than the bridge deck surface.

The foregoing problems fairly well precluded the possibility of any snow and ice sensor activating a motorist warning sign. However, in that all preparations were made to conduct the experiment as well as a need to visually verify the sensor performance, the test was conducted in March/April 1975. The actuated sign or motorist warning system was operated via manual switching, although a snow and ice sensor triggered system was possible via another switch key position.

In the motorist warning system test, two activated signs were installed on each approach to the Prosser Creek Bridge. Pictures of the two signs appear in Section 5 of this report. Over the 28-day test period, there were fourteen separate hazardous bridge conditions. There was one black ice event and one frost event where the bridge deck was only partially covered. The remaining twelve events were instances of slush, snow or ice accumulation. The duration of these events ranged from slightly over one hour in length to more than 46 hours in duration.

Despite small vehicle sample sizes the results of impact analysis of the signs on vehicular speeds was significant. The ability to analyze the significance can be attributed to the capability of the data acquisition system to track an individual vehicle through a sequence of three speed traps on the north approach to the bridge. This, coupled with a headway calculation capable of discerning vehicles in a car-following mode, allowed for speed analysis over individual independent vehicular speeds. Within the data system is the capability to discern

opposing traffic on the two-lane bridge in instances where this traffic would possibly influence southbound vehicular speed. Therefore, it was possible to disregard the speed observations of vehicles so influenced.

There were three sensor system failures during the 28-day test period. The two Cytronics systems did not fail; however, it had been quite well established that the system was not an ice and snow detector but a frost detector and their poor performance in this environment was expected. One SSI system operated throughout the test; however, its poor performance relative to false alarms may be partially attributed to almost constant contact with salt water, although this is only a hypothesis. The sensor did, however, completely miss events.

Detailed discussion of the sensor performance and the motorist warning sign impact on traffic speeds is contained in Section 5.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon results obtained over two winters' testing, the motorist warning test and numerous installation and calibration problems, a number of conclusions can be drawn. These conclusions are:

a) It is doubtful that direct snow, ice, or frost instrumentation, at reasonable cost, can be perfected to accurately forecast or sense snow, ice slush and frost on a bridge structure. Accurate forecasting or sensing of a condition in this context is defined as information which is 99 percent correct with respect to skidding hazards with a negligible false alarm rate. Such performance requirements are considered necessary in order to transmit consistent information necessary to the utility of such a warning system.

b) Were such instrumentation developed, it would be necessary to sense the surface condition in more than one region of the bridge deck. Onset and termination of events rarely occur in a uniform manner over the surface area. In fact, some skidding hazard events are limited solely to a single area or section of the bridge.

c) The degree of reliability required for any snow, ice and frost sensing system is dependent on both the type of warning to be transmitted and the recipient of that information. In the case of the driving public, the information could warn of a possible hazard or hazardous condition. In such a case, the detection probability should be high; however, the false alarm would be less critical than for the case where the warning declared existence of a specific condition. Appendix A discusses this subject in greater detail.

d) The Cytronics system can be considered, from its design, to be at best a frost detection system only. However, its performance at frost detection is unproven. The single frost event occurring during the motorist warning system test went undetected by all sensors.

e) The Holley system is in need of further development. It is felt that higher quality components with closer tolerance specification would improve the system performance. The heater burnout problem and thermistor failures must be solved before any serious consideration is given to further development. A detailed tolerance analysis should be conducted to determine if the existing design can be calibrated simply. This tolerance or error analysis is particularly applicable to the frost anticipation mode. It was this mode which was slightly modified by MBA to provide actual frost detection capability.

f) The SSI system has been improved in certain performance characteristics through efforts of the manufacturer. Although performance is not yet at the level sufficient for use in activating a motorist warning system, continued improvements could bring it to that level. There are some unanswered, serious questions relative to the ability of the epoxy head to withstand the roadway environment and the problem of the witness plate being colder than the road surface itself. Numerous cases of frost formation on the head were observed over both winters' test periods. These events rarely were accompanied by frost on the bridge deck.

g) The Prosser Creek test site has proven to be an excellent location for testing of the snow and ice sensing system capabilities, although few verified frost conditions occurred.

h) Traffic speeds profiles are probably the most reliable single source of information relative to roadway conditions.

i) Significant vehicular decelerations were produced by the pair of activated warning signs (Appendix C). The conspicuity of the alternate flashing amber lights atop the bridge-located sign was likely the most significant factor in effecting the reduction in bridge speeds which, in turn, produced desirable safety benefits. However, the message content of the bridge sign is considered to be undesirably in a practical application since the non-activated flashers could be construed to imply a safe bridge condition. Should an accident occur

under these conditions, a non-detected icy bridge would potentially produce a liability problem. The advanced warning sign with its "Bridge Ahead" message in a non-activated mode and "Icy Bridge Ahead" message in an activated mode is considered a more desirable warning sign. If the amber flashers were mounted atop this sign and activated with the lighting of the word "Icy," the conspicuity, or attention-getting, quality of the sign would be greatly increased.

j) A reliable activated signing system will produce desirable speed reductions at most levels of approach speeds.

The primary recommendations arising from the program are:

a) More consideration should be given to sensor system reliability and flase alarm rate and the resulting impact on the effectiveness of a motorist warning system. This would result in fewer incorrect messages being communicated to the motorist.

b) Distinct levels of activated hazard warning systems should be developed consistent with the motorist's informational needs necessary for safe response to the hazard. A greater need for specific hazard information and likelihood of the occurrence of the hazard is normally accompanied by tighter system requirements to hazard detection and false alarm rates.

c) Consideration should be given to other composite hazard sensing systems whenever accuracy and hazard specifics are required, e.g., environmental sensing as well as traffic sensing.

d) Snow, ice and frost hazards do not occur uniformly or spontaneously. Such events should not be considered as either a dry road, non-hazardous situation, or a fully covered hazardous road.

4.0 PHASE I - FIRST YEAR OF TESTING

4.1 Detector Requirements

Any successful snow, ice and frost detector system would have to satisfy the following requirements:

1. It should be suitable for use with at least one of the following countermeasure systems:

   a. Motorist warning system with variable or activated message signs

   b. Snow and ice removal crew alert system

   c. Automatic deicing systems, which could involve chemical spray or road/bridge heating

2. It should reliably detect at least one of the following conditions of the roadway or bridge surface:

   a. Snow

   b. Ice

   c. Frost

3. The system should detect the road surface condition, subject to the following additional requirements:

   a. The system should function in the presence of deicing chemicals.

   b. The system should be compatible with standard snow removal equipment.

4. Some threshold level of functional reliability should be met, relating to frequencies of missed alarms and false alarms, and relating both to the onset and the cessation of the hazard condition. Also, the amount of time lead or time lag allowed for correct detection of an event should be included in the reliability requirement. The specific requirements would be on the operational use intended, i.e., as listed in Item 1 above.

Item 2, condition to be detected, has been stated so that a system which detects snow and ice but not frost could qualify, and vice versa. Many parts of the United States encounter significant frost hazard frequency but little snow; other parts require snow detection but not frost protection. Also, the requirement may vary depending on the particular highway system countermeasure strategy. The ideal detector system should be able to detect snow, ice and frost, but it turns out in practice that the meteorological conditions associated with snow and ice as opposed to frost are different, and the various candidate detectors MBA has screened may be suited to one and not the other.

For a particular system that can gain widespread use, the constraints of Item 3 appear necessary. Deicing chemicals are used so widely that a detector unable to function in the presence of deicing chemicals would be quite restricted in the number of highway systems in which it could be used. Also, in geographical areas that experience snow, snow plows are almost always used. This rules out detectors that have elements that must protrude above the surface of the roadway.

In the statement of detector performance requirements, notice that two terms were used.

a. Surface. The actual road surface conditions are desired, because these consitute the hazard. Thus, systems which measure conditions nearby but not actually on the surface may be of little use. This is especially true when the road surface is covered with deicing chemicals, but the bridge side structures are not.

b. Detection. Here, detection is contrasted with prediction. In general, MBA has felt that actual detection of the road condition is necessary rather than mere prediction. One sensor MBA installed (Holley) included prediction of frost in addition to actual detection of snow and ice.

4.2 Detectors Screened

MBA selected nine detection systems before making its final selection of the units to install in the experiment. These nine systems are briefly described as follows:

1. Cytronics Frost Detection System, (Solid State Model 1973A), manufactured by Cytronics, P. O. Box 392, Ames, Iowa 50010, telephone 515-232-2733. The principal engineer is Mr. Paul Poppe. The unit detects frost by applying a thermal pulse to a witness plate and noticing a delay in temperature change due to absorption of latent heat of melting. The unit has been continually improved as a result of testing by the Iowa State Highway Commission. The price is $1,525.

2. Surface Condition Analyzer (SCAN), manufactured by Surface Systems, Inc. (SSI), P. O. Box 9927, St. Louis, Missouri 63122, telephone 314-822-2678. The principal engineer is Mr. Wilson W. Overall. The unit detects a moisture or ice layer on a witness plate by a change in capacitance compared to air alone. It discriminates between ice and moisture with a conductivity probe. Wyoming and Illinois highway agencies were enthusiastic about this unit. The price is $3,000.

3. Radiometer, being developed by Minneapolis Honeywell. Key development contact was Dr. George Webber, telephone 612-331-4141, extension 5715; the key marketing contact was Mr. Jerry Maylan, extension 4300. The device measures spectral temperature at 1.6 cm wavelength. Spectral temperature is the product of actual temperature and surface emissivity. Dry pavement emissivity should be around .8, that of ice around .4, and that of water around .1. The device was scheduled to be developed by December 1973, and production units will be available around 1977. Production unit costs were not available.

4. Holley Highway Ice Detector System, Model 67205, manufactured by the Holley Carburator Division of Colt Industries, 11955 East Nine Mile Road, P. O. Box 749, Warren, Michigan 48090,

telephone 313-536-1900. The marketing contact was Mr. J. G. O'Connell. This unit detects ice when the road is below 32°F by noting a conductive imbalance between an unheated and a heated probe (the heated probe is above 32°, so as to melt any ice). The unit also uses a humidity sensor to predict frost. Testing by several states had yielded mixed results. During conduct of the project, Holley discontinued production. The rights to this system have since been sold to Meteorology Research, Inc.

5. Econolite Ice Moisture Detector. A license to manufacture and sell this unit was extended to Mr. Ray Cabe, Sesco Corporation, 1099 N. Batavia Street, Orange, California 92667, telephone 714-997-2262. Mr. Cabe was formerly with the Econolite Division of Tamar Electronics, owner of the rights. Mr. Cabe has considered development of an improved unit. The principle is conductive imbalance between unheated and heated probe with road temperature below 32°F. New unit price is not available.

6. Icelert Road Ice Detector, manufactured by Findley, Irvine Limited, Bog Road, Penicuik nr Edinburgh, Scotland. Marketing in the United States is conducted by Roytran Internation Corporation, 179 North 10th Street, Brooklyn, New York 11211, telephone 212-782-1505. The marketing contact was Mr. Donald L. Botway, President. The principle is the same as that of the Econolite. The price of a Mark II unit with salinity detector option is $1,077.

7. Nelson Snow Detector System, Unit Number SNO-41, manufactured and marketed by Nelson Electronics Division of Sola Basic Industries, P. O. Box 726, Tulsa, Oklahoma 74101, telephone 918-627-5530. The contact was Mr. Robert Kubiki. The unit detects ice by sensing surface temperature below 32°F and conduction on a heated probe. It cannot give a correct report when deicing chemicals are applied as the countermeasure.

8. Hinrichs Ice Detector, developed and sold by Mr. Bert Hinrichs, P. O. Box 339, Shelbyville, Indiana 46176 (926 Hampton Blvd.), telephone 317-392-2443. His representative was his patent layer, Mr. William R. Coffey, 202 Hume Mansur Building, Indianapolis,

Indiana 46204, telephone 317-637-5531. In this system, a temperature sensor and three temperature-humidity sensors detect conditions favorable to ice, snow and frost formation. Thus, the system is predictive in nature. New units purchased for this program would have cost around $1,400, and in production quantities, the unit could cost $850.

9. Rosemont Ice Warning System, manufactured by Rosemont, Inc., P. O. Box 35129, Minneapolis, Minnesota 55435, telephone 612-941-5560. The contact was Mr. William Zimmerman, Marketing Engineer. Exclusive rights to sell the unit for highway applications were held by Mr. Sam Dunn, Fosco Fabrication, P. O. Box 200, Dixon, Illinois 61021. This system detects snow and ice buildup on a vibrating element by noting a drop in vibration frequency.

4.3 Final Detector Selection

MBA eliminated four of the candidate detector systems for the following reasons:

1. The Rosemont system (Number 9) was considered intrinsically inadequate because the system cannot compensate for deicing chemicals or road heating by tire action. This is true because the unit must be mounted on the bridge railing, or somewhere other than on the actual roadway surface, since it would protrude above the surface.

2. The Nelson system (Number 7) was eliminated from this program because it does not function correctly in the presence of deicing chemicals.

3. The Hinrichs system was eliminated because it was predictive.

4. The Icelert system was eliminated because it is manufactured abroad and MBA feared that the manufacturer could not be sufficiently responsive if MBA required factory field service. Since the function of the unit was similar to that of the Holley and Econolite

systems, it was felt that these two American designs would be sufficiently representative of the type of detectors that employ the principle of conductive imbalance for detection of the hazard.

MBA had hoped that it could include all five of the surviving units in its study. However, the Econolite unit was no longer being manufactured and sold, and any unit included in the MBA experiment would have had to have been a special custom item. Also, Mr. Cabe, the vendor, felt the unit needed upgrading by minor redesign. Mr. Cabe ultimately decided not to pursue development and marketing of the unit, and he declined to furnish a unit for the MBA experiment. In addition, the Honeywell radiometer was still in the development stage, and Honeywell was asking for $25,000 for fabrication of two development prototype units to be included in the MBA experiment. This price was considered too high, and the unit was not included in the experiment.

The justifications for the three surviving systems were as follows:

a. Cytronics Frost Detection System. This unit was included in the previous DOT snow and ice detector study. It is specifically designed to detect frost, which could not be detected adequately by conductivity devices. Prototypes for the system were first developed by the Iowa State Highway Commission. The unit has been continually upgraded as a result of on-going testing in Iowa. The Iowa highway authorities were pleased with the current performance of the unit. The on-going R&D program to validate performance in Iowa appeared to be proceeding in an orderly and systematic fashion. The device was the only one of its type, namely, detection of ice by observing melting temperature plateau during a thermal pulse.

b. Surface Condition Analyzer of Surface Systems, Inc. Two states showed considerable enthusiasm for the unit (Wyoming and Illinois), and Michigan was about to test it. It was a genuine second generation system, in that it was developed to overcome disadvantages that previous evaluations showed inherent in conductivity devices. The

unit had performed satisfactorily in airport demonstration tests. The device was the only one of its type, namely, detection of moisture or ice layers by capacitance. Since it has no heated elements, the inventor calls it "nondestructive" in contrast to the conductivity devices that work with deicing chemicals, and in contrast to the thermal pulse device.

c. Holley Highway Ice Detector System. This unit was representative of the first generation conductivity ice detectors that can work in the presence of deicing chemicals. (The two other candidates of this type were the Econolite and Icelert systems.) The Holley, in addition, has a humidity detector which may make it possible for it to detect frost inferentially. The Holley system had been evaluated by several states. Michigan has found it satisfactory in performance. Illinois, Oklahoma, Pennsylvania and Wyoming had reported not altogether satisfactory results from recent tests, mainly because of reluctance of the company to service the units when they fail to perform during testing. MBA was satisfied that it could get satisfactory service from the vendor. MBA selected the Holley unit as representative of the conductivity type detector.

4.4 Site Selection

MBA's program staff felt that one of the most important tasks in the entire program was the selection of an appropriate site for the conduct of the test and evaluation. The outcome of the entire program could be greatly influenced by this selection. Thus, a considerable effort was devoted to the process of rigorously screening virtually all the bridges in California's severe environment area. This section will describe this effort beginning with the site requirements, the screening process and finally a description of the selected site.

4.4.1 Site Requirements

In order to meet all of the requirements of the overall program, it was felt that the bridge must possess the following characteristics:

a. High frequency of ice, snow and frost
b. Two lanes
c. Uncomplicated approach and departure
d. Moderate traffic flow
e. Length greater than 100 feet
f. Moderate maintenance by snow removal crew
g. Nearby power and telephone service
h. Observer location shielded from view of motorists
i. Reasonable accessibility.

These requirements are listed in their approximate order of important. It was recognized, however, that a gross deficiency in any of the features could seriously affect the program.

The need for high snow, ice and frost frequency is obvious since a major aspect of the program is the operational evaluation of ice, snow and frost detection systems. The reliability of these devices is measured by the frequency with which they respond correctly. The confidence in that apparent reliability is indicated by the number of correct responses. Since the motorist warning system portion of the program involves some degree of responsibility regarding valid information, high reliability at high confidence level is required.

The requirement for a two-lane road arises from the motorist warning system study. This type of road minimizes the number of variables to be considered and simplifies the speed data reduction and analysis.

The uncomplicated approach and departure geometry was felt to be important since it eliminates unusual or unanticipated motorist behavior in the test section.

The State of California has an extremely aggressive winter maintenance policy in the severe enviornment area. During a storm, however, the priorities are such that the major interstates receive the brunt of the service initially, thus the secondary roads seemed more

appropriate for this program since the snow or ice coverage on the bridge remains unperturbed for a longer period. This allowed the detectors to both detect the onset and remain in the alarm status until clearance begins.

The need for nearby telephone and power service is obvious, due to the amount of electronic equipment involved.

Since it is one of the tasks of the observer to actually watch the vehicles approach and pass over the bridge, a clear view must be provided from the instrument trailer. On the other hand, it is desirable that the trailer not distract the driver as he approaches the bridge. This imposes a somewhat unusual constraint which was necessarily borne in mind during the selection process.

4.4.2 Selection Process

The site selection process consisted of a series of six screening steps which finally yielded acceptable candidates. The first step was to acquire a copy of the "Bridge List and Log of State Highways" for the severe environment area, compiled by the Bridge Maintenance Section, California Division of Highways. The useful information contained therein was bridge location and length. All bridges less than 100 feet in length were rejected. Only two-lane bridges were considered.

The longer bridges were then located on a map and their elevation determined. All bridges below 4000 feet were rejected because of insufficient ice, snow and frost events. The Average Annual Daily Traffic and Peak Traffic for the surviving bridges were then determined from "1972 Traffic Volumes on California State Highways." Those with AADT of less than 1000 were rejected due to the risk of insufficient winter traffic. (The peak typically occurs in the summer months.)

The general areas in which the surviving bridges were located were then checked for winter weather conditions. This led to the rejection of several more candidates due to generally mild winter weather.

The remaining sites were then checked for alignment and any other peculiarities which could adversely affect the experiment. This was accomplished by first viewing the Photo-log* footage made available by the California Division of Highways. This resulted in the rejection of another set of bridges.

The Principal Investigator then personally visited and inspected each surviving site location. The purpose of these visits was to determine possible instrument trailer locations and any changes such as current construction which may have taken place since the Photo-log footage was taken. Additionally, the availability of power and telephone service was checked.

The final event in the selection process was the determination of the local weather at the exact location of the bridge.

4.4.3 Selected Candidate

Using the process described above, final bridge site selection was made. The Prosser Creek bridge, located approximately five miles north of Truckee, California, on State Route 89 was selected. Table 1 gives some of the relevant characteristics of this bridge along with those of a number of other candidates. The right hand column indicates the reason for rejection. Figure 1 is a map of the region in which the candidates are located. The numbers key to Table 1. Of the fifteen sites listed, ten were visited by a member of the program staff.

Bridges 1 and 10 survived all screening steps and the final determination between the two was made on the basis of local weather histories. Table 2 lists the local weather for a ten-year period and is based on the U. S. Climatological Survey for California. The data for Susanville was taken as representative of Bridge 10. The

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* Photo-log--35 mm films made up of slides taken every 52.8 feet along State highways. The coverage is from both directions and includes virtually all highways in the State.

TABLE 1

CANDIDATE BRIDGE SITES

MBA #	Bridge #	Name or Description	Post Mile	Dist.	Co.	Rte.	Structure Type	Length	Width	Year	Elev.	AADT	PADT	Comments
1	17-78	Prosser Creek	00487	03	Nev	89	CGC	131	28	61	5,600	1,130	2,500	
2	19-32	Truckee River	01306	03	Pla	89	CG	162	24	29	6,000	5,200	10,500	Poor Geometry
3	25-15	Up. Truckee River	07266	03	Ed	50	CG	120	44	36/69	6,300	10,800	18,800	Turn Lanes, 50 mph
4	25-12	Up. Truckee River	07031	03	Ed	50	CG	100	26	41	6,300	7,400	9,900	Turn Lane
5	13-7	Salmon Creek	R03290	03	Sie	49	CGB	252	32	64	4,800	500	1,200	Traffic Too Low
6	17-36	Rts 89, 80 Sep	00056	03	Nev	89	CGC	214	40	59	5,800	1,600	1,900	Overpass
7	03-5	Pit River	01795	02	Mod	299	CGC	305	32	62	4,700	950	1,400	Traffic Too Low
8	03-52	SFK Pit River	R01652	02	Mod	395	CSC	170	40	71	4,400	1,200	1,750	Weather
9	06-52	Lake Britt Br.	02919	02	Sha	89	STDCG	580	24	38	4,000	900	1,100	Traffic Too Low
10	07-46	Susan River	R01738	02	Las	36	CGB	285	32	66	4,700	2,000	4,900	
11	08-94	Battle Creek	08148	02	Teh	36	SGA	211	32	58	4,796	1,150	1,750	Construction
12	08-62	NFK Deer Creek	R09892	02	Teh	36	SGA	315	28	66	4,700	800	1,900	Traffic Too Low
13	09-6	Bailey Creek	R01373	02	Pla	36	CGB	203	40	66	4,500	2,000	4,900	Turn Lanes
14	09-44	Lake Almanor S	02997	02	Pla	89	CGB	467	28	63	4,500	620	1,490	Traffic Too Low
15	09-65	Hamilton Bran	00898	02	Pla	147	SGD	322	24	48	4,700	1,150	1,450	Too Narrow

FIGURE 1
CANDIDATE BRIDGE SITES

data for Prosser Creek is an extrapolation from two weather stations each located about seven miles from the bridge. A review of Table 2 shows clearly that more suitable weather exists at Prosser Creek. The mean daily minimum temperature at Prosser is significantly lower than at Susan River. This is important to insure frost events when deicing chemicals are routinely used. Further, Prosser Creek has almost twice the precipitation and a greater number of major events.

Due to the rugged terrain in which some of the bridges were located, general area weather histories do not necessarily depict the conditions several miles away from the weather station. The local weather history for the sites was compiled from National Weather Service publications; when available the use of experienced local meteorologists familiar with the areas. It was on this basis that final site selction was made.

Figure 2 is a photograph showing the Prosser Creek bridge from the side. Figure 3 is a reproduction of a contract map of the area which shows the approach and departure geometry of the bridge. Southbound traffic can see the bridge from about 900 feet away, while northbound traffic has a clear view for more than a mile.

The terrain to the south of the bridge falls away on either side of the road which would make observation difficult. On the north side an elevated site exists which provides a clear view of the approach and the bridge deck. That site is essentially obscured from the approaching southbound traffic by a large fir tree.

The sequence of photographs in Figure 4 shows the motorist view as the bridge is approached from the north. The bridge first comes into view in Figure 4c.

The Average Daily Traffic on this section of highway was last measured in 1970 with the following results for the southbound lane: January, 250; April, 220; July, 1180; October, 700. It is clear that the traffic falls off dramatically during the winter months. Based on this

TABLE 2

WEATHER SUMMARY

Mean Daily Temperature

		Nov	Dec	Jan	Feb	Mar
Prosser Creek (Bridge #1)	Max (°F)	50	40	36	39	45
	Min (°F)	20	15	12	14	18
Susan River (Bridge #10)	Max (°F)	52.3	42.2	39.6	45.1	52.1
	Min (°F)	24.6	20.2	20.5	21.9	25.4

Precipitation

Prosser Creek	Total Snowfall (in.)	13	31	49	45	37
	Total Precipitation (in.)	3.1	5.65	6.15	5.25	4.0
	# of Days ≥ 0.1"*	3	6	9	8	7
Susan River	Total Snowfall (in.)	1.9	12.1	21.4	11.4	7.5
	Total Precipitation (in.)	1.51	2.56	2.53	2.51	1.51
	# of Days ≥0.1"	3	5	8	6	4

* Number of days with precipitation greater than or equal to 0.1 inch.

FIGURE 2
PROSSER CREEK BRIDGE

FIGURE 3
ROAD GEOMETRY AT
PROSSER CREEK BRIDGE

C)

B)

A)

FIGURE 4
MOTORISTS' VIEW OF TEST SECTION

E)

D)

FIGURE 4 (cont'd)
MOTORISTS' VIEW OF TEST SECTION

information, one could expect an ADT of about 250 to 300 for a November through March observation period. This means that data will have been taken on 37,500 to 45,000 vehicles during each season, which should be ample for the motorist warning system study.

4.5 Data Acquisition System

In order to properly conduct the detector evaluation and warning system study, it was felt that the following items of data should be taken and recorded:

a. Detector status
b. Temperature
    - Air
    - Roadway
    - Bridge deck
c. Dew point
d. Precipitation
e. Wind speed
f. Wind direction
g. Illumination level
h. Vehicle speed (three stations)
i. Vehicle type (car versus truck)
j. Presence of opposing traffic

Figure 5 shows a block diagram of the fully automatic data acquisition system configured for and used in the field tests. It can be seen that the system provides for 48 channels of digital input and 16 channels of analog input. The primary processing system (a Nova 1210 minicomputer) accepts this input, reduces it to sensible form and provides teletype and light board displays as well as a permanent record on paper punch tape. The data on the paper tape can then be brought to MBA's San Ramon facility for automatic data analysis. The system is also capable of accepting and recording input from the on-site observer via the teletype keyboard. Observer input consists of:

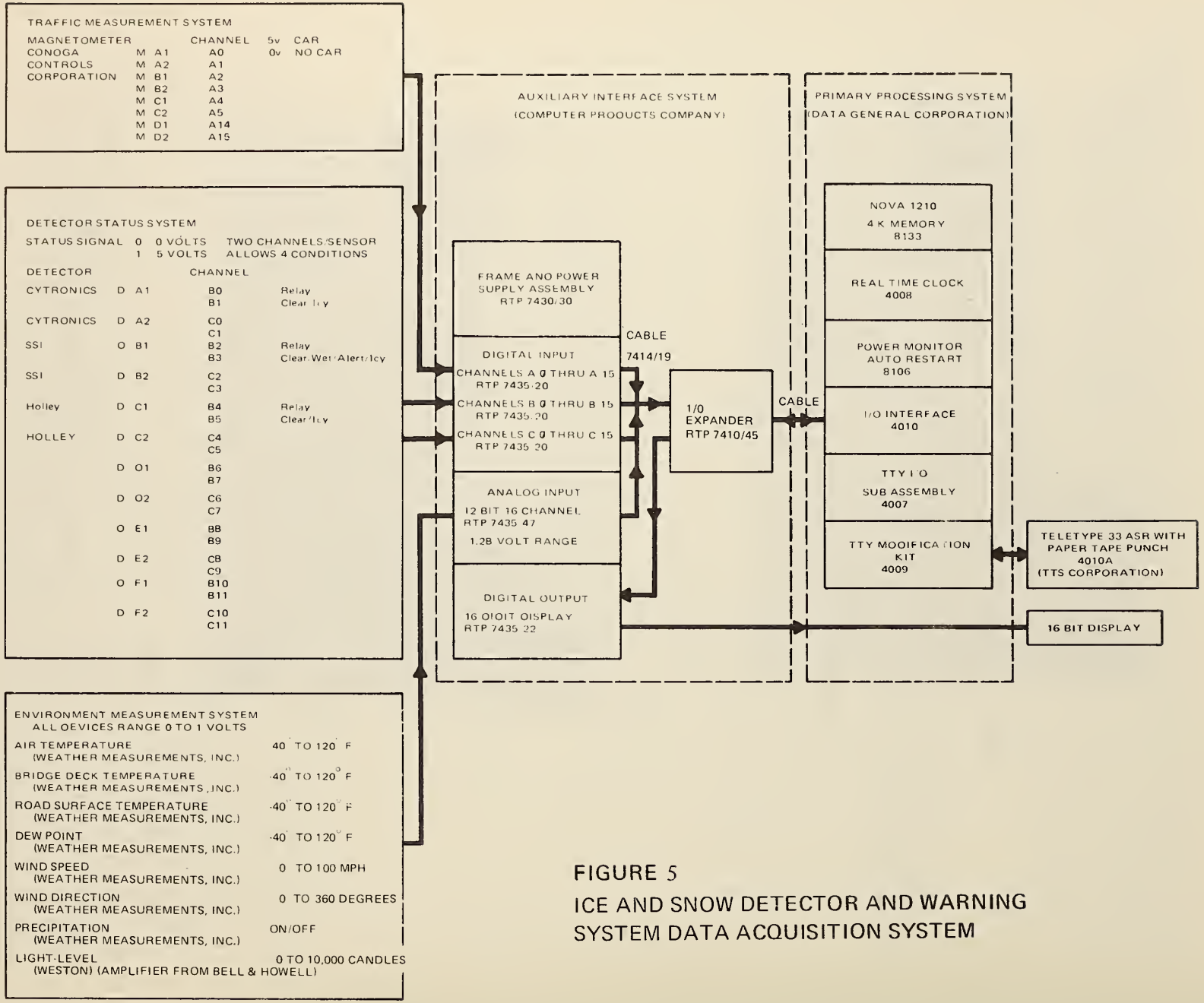


FIGURE 5

ICE AND SNOW DETECTOR AND WARNING SYSTEM DATA ACQUISITION SYSTEM

a. Bridge deck condition
b. General weather
c. Presence of any material on each sensor head
d. Number of vehicles observed
e. Number of brake lights observed

The system was designed to run continuously on a 24-hour-a-day basis. The computer program to handle data acquisition and preliminary reduction is described in Volume II of this report.

4.6 Site Configuration

Figure 6 shows the overall test site configuration. The site is on State Highway 89N, 4.96 miles north of the I-80/89N junction (Truckee, California). The elements of the installation are the instrumentation/observation trailer, the ice and snow detectors, and the traffic measurement stations. Only the southbound traffic was included in the speed measurements. The elements of installation are described below.

4.6.1 Instrumentation/Observation Trailer

The purpose of the trailer was to house the data acquisition system and the environmental measurement equipment. It also provided a location from which the observer could operate. Figure 7 is a schematic showing the location of the trailer relative to the bridge and road. The trailer itself is shown in the photograph (Figure 8). The trailer is surrounded by an eight-foot-high chain link fence for security purposes. The weather mast can be seen mounted atop the trailer. Mounted on the mast is the wind speed/direction indicator, dew point cell, air temperature thermistor, and the illumination meter. The precipitation detector is mounted in the right hand corner of the security fence.

The trailer is a 16.5-foot Shasta and has ample space for the observer activity and instrumentation. Figure 9 shows the floor plan and the location of the equipment. The photograph (Figure 10)

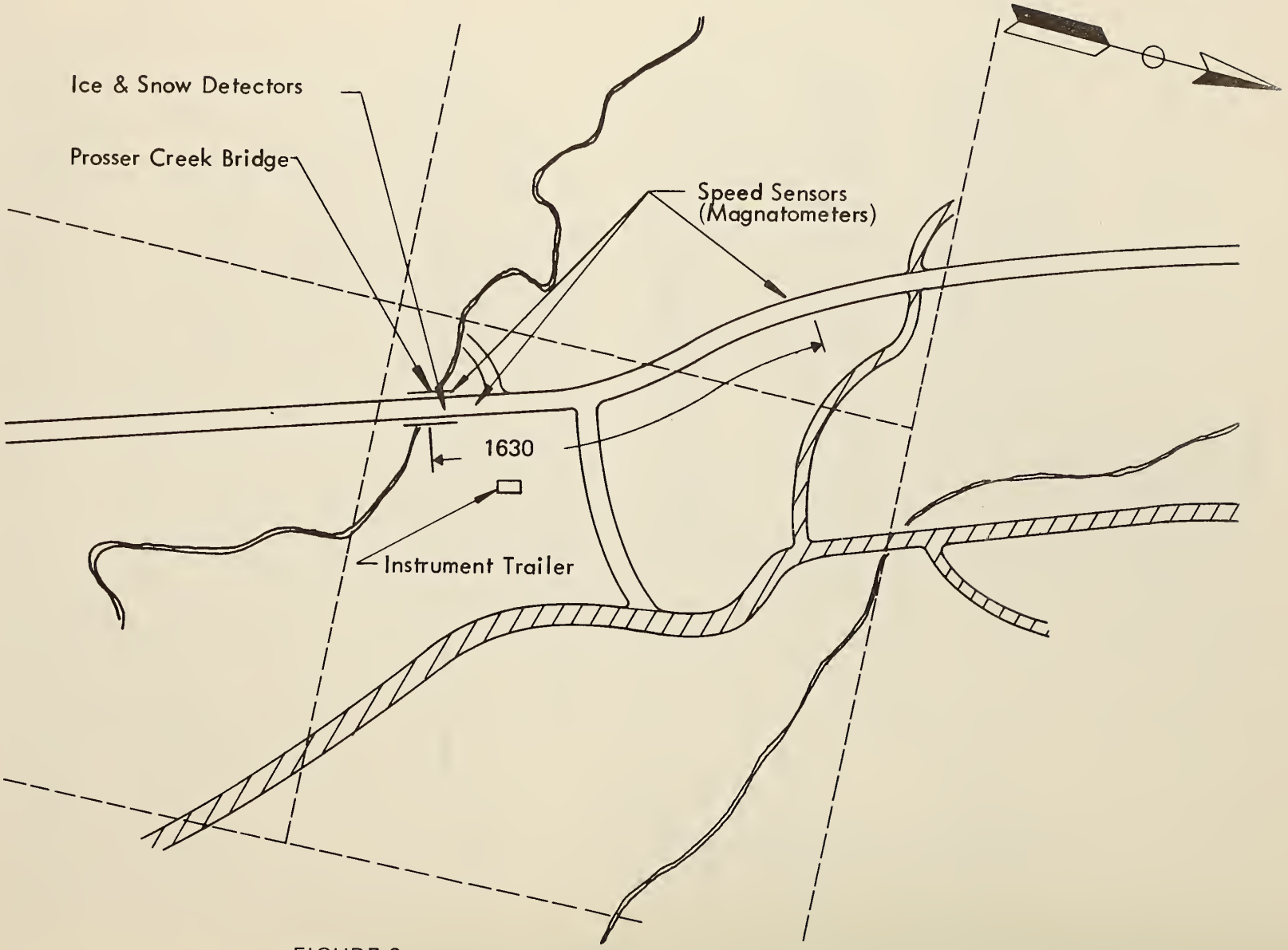


FIGURE 6
OVERALL TEST SITE CONFIGURATION

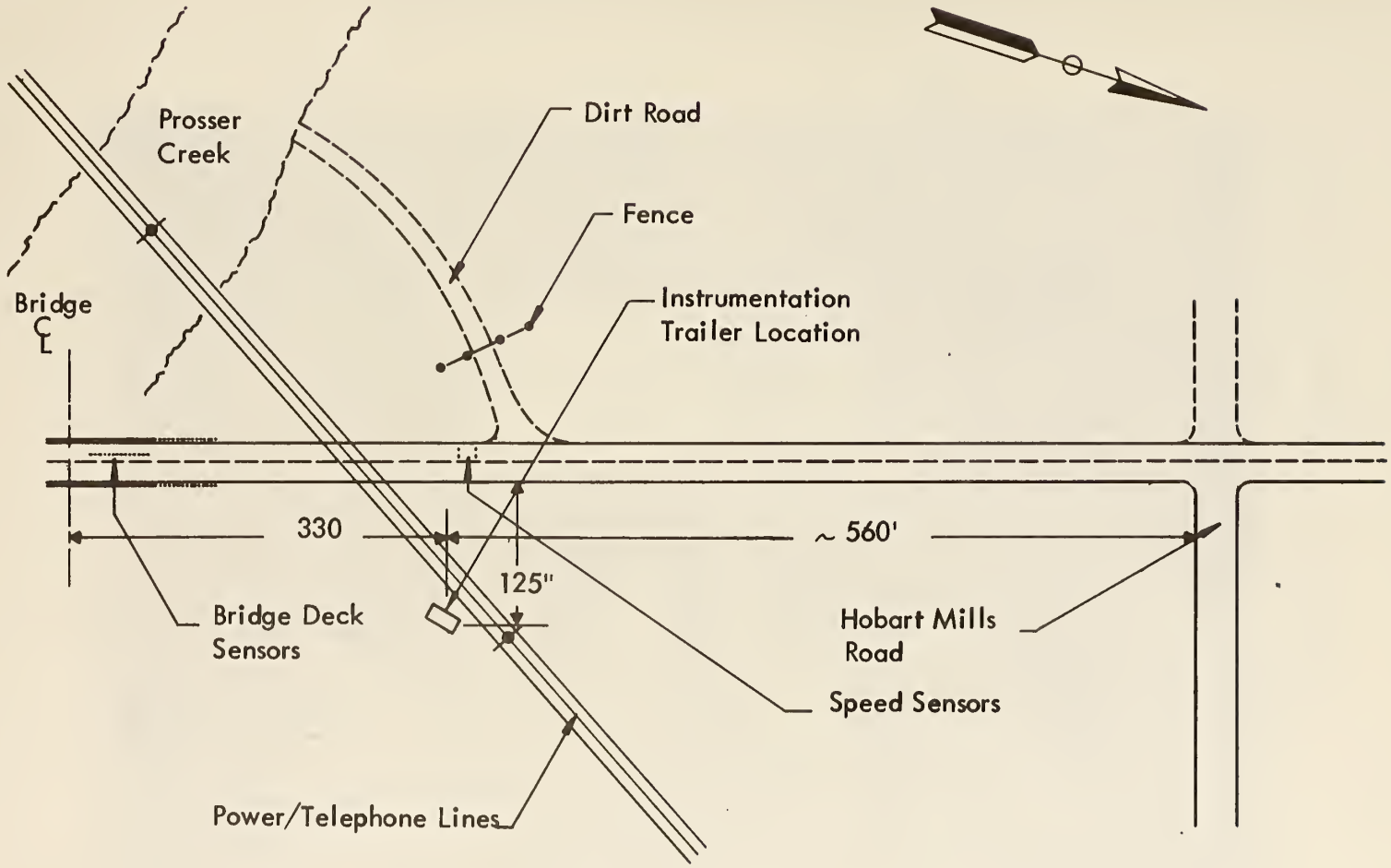


FIGURE 7
PROSSER CREEK BRIDGE

FIGURE 8
INSTRUMENTATION/OBSERVATION TRAILER

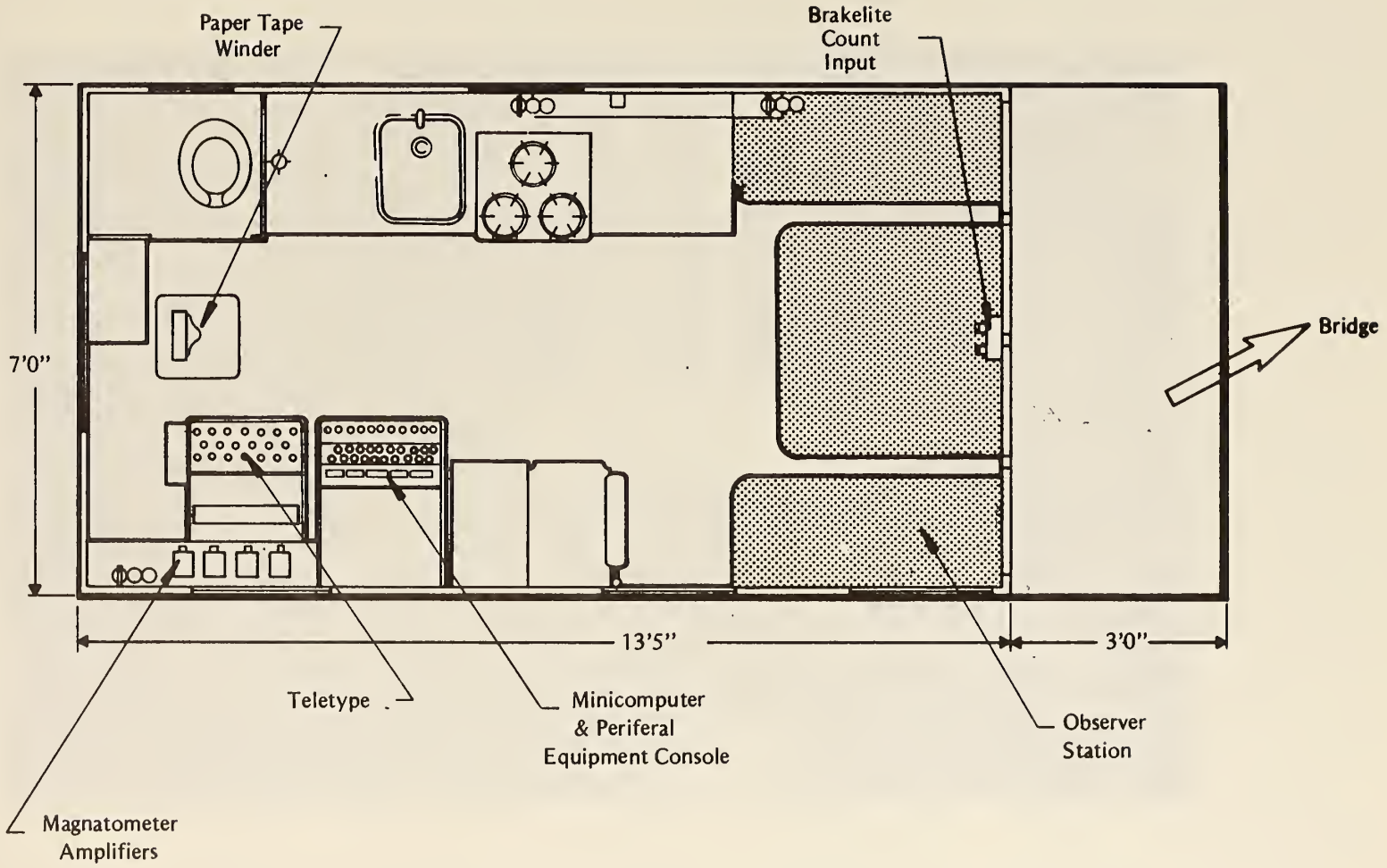


FIGURE 9
FLOOR PLAN INSTRUMENTATION/OBSERVATION TRAILER

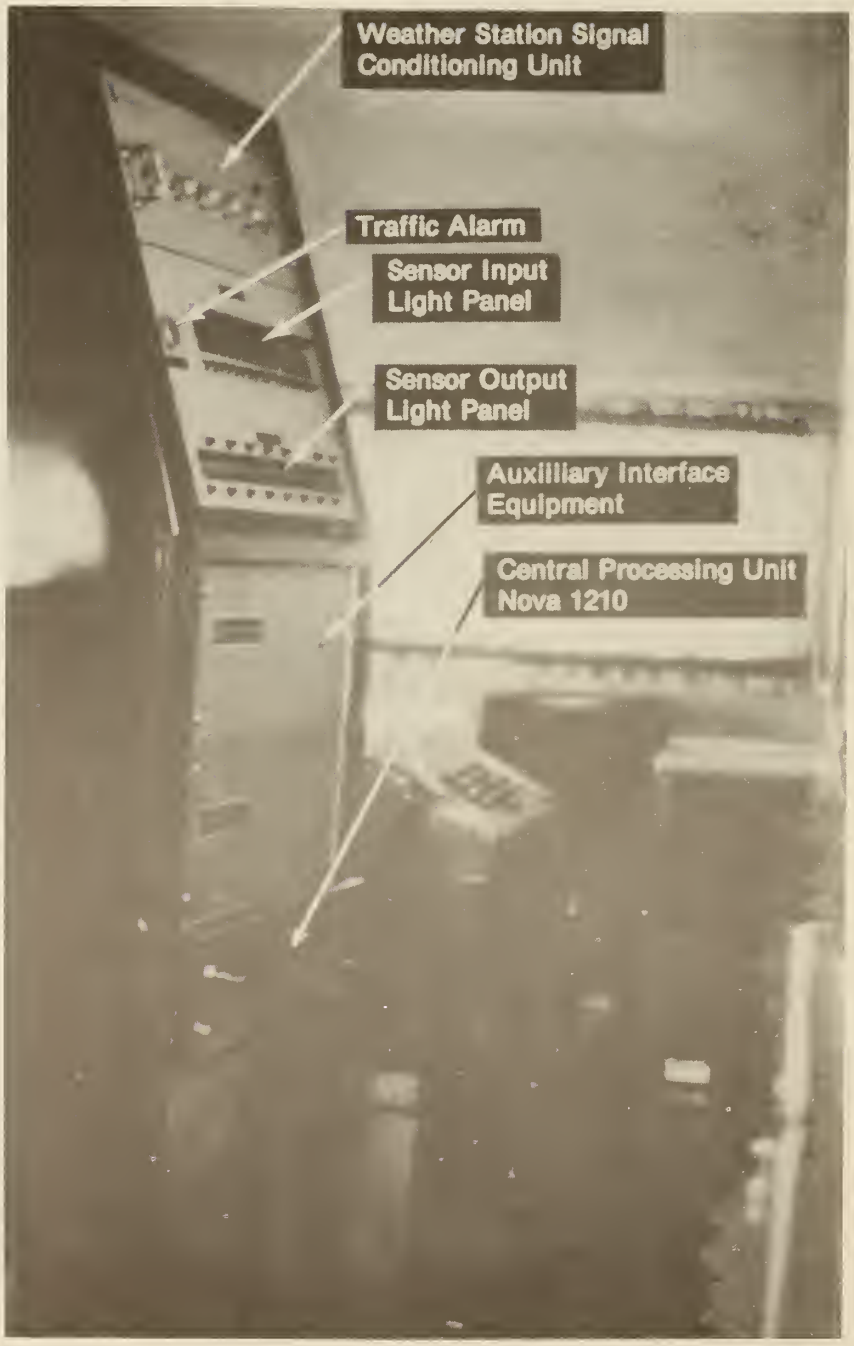


FIGURE 10
DATA ACQUISITION SYSTEM CONSOLE

shows the computer console, teletype and tape winder. The trailer was provided with electric heaters to maintain safe operating temperature for the equipment. Butane heat was provided as a back-up in the event of power failure. The trailer was oriented on the site such that the observer had an unobstructed view of the approach to the bridge and the bridge deck itself. This can be seen in Figure 11. The trailer was actually located on National Forest land which required the securing of a Land Use Permit from the U. S. Forest Service.

4.6.2 Ice and Snow Detectors

Two sets each of three different brands of ice and snow detectors were installed on the Prosser Creek Bridge. Each system consisted of a controller and one or more bridge deck sensors. In addition, the Holley detector had a humidity and air temperature device mounted separately. In order to simulate actual operational conditions, the controllers were mounted at the bridge exposed to the weather, rather than in the instrumentation trailer. The controller installation can be seen in Figures 12, 13a and 13b. The first photograph shows the entire installation as viewed from across the creek. All of the controllers were mounted on plywood panels against the northern abutment. The SSI and Cytronics controllers are seen on the left and the Holley on the right. Figure 13a shows a close-up of the Holley installation along with 110V distribution system. Figure 13b shows the Cytronics controllers (upper boxes) and the SSI controllers (lower boxes).

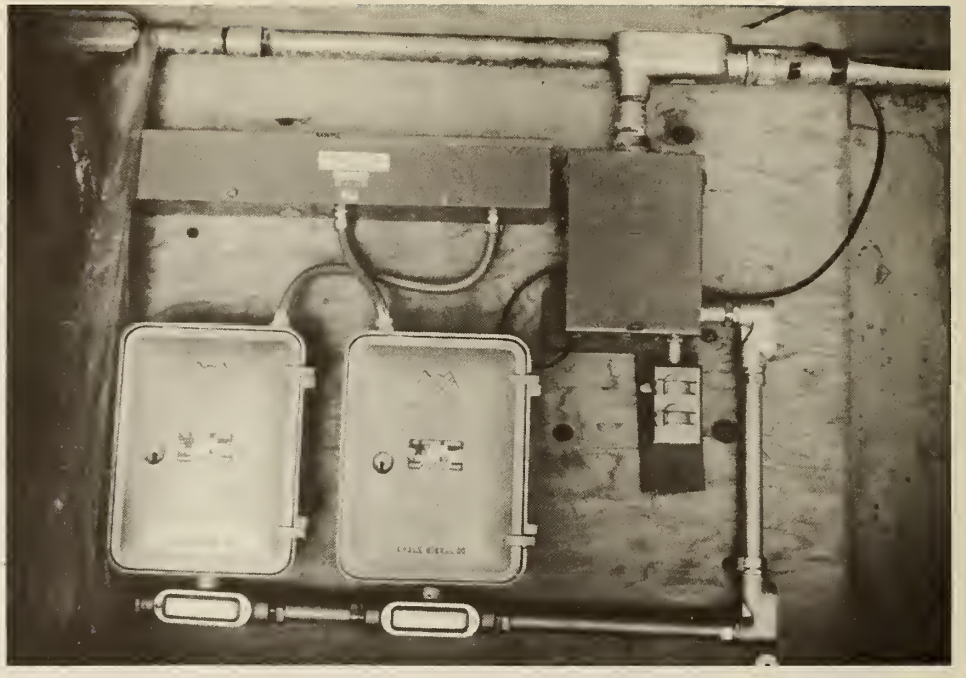
As mentioned, the Holley system required an additional component; a humidity and air temperature sensor. These devices were mounted on the outside of the bridge adjacent to the bridge deck sensors. The installation is shown in Figure 14.

The bridge deck sensors were installed according to the schematic shown in Figure 15. The actual installation is shown in Figure 16. It can be seen that the line of sensors is 5'8" from the centerline. This is approximately the center of the tire tracks when

FIGURE 11
INSTRUMENTATION TRAILER WITH
VIEW OF BRIDGE DECK

FIGURE 12
ICE DETECTOR CONTROLLER
ON BRIDGE ABUTMENT

A) HOLLEY



CYTRONICS

B)

SSI

FIGURE 13
ICE AND SNOW DETECTOR CONTROLLERS

FIGURE 14
HOLLEY HUMIDITY/AIR
TEMPERATURE SENSOR

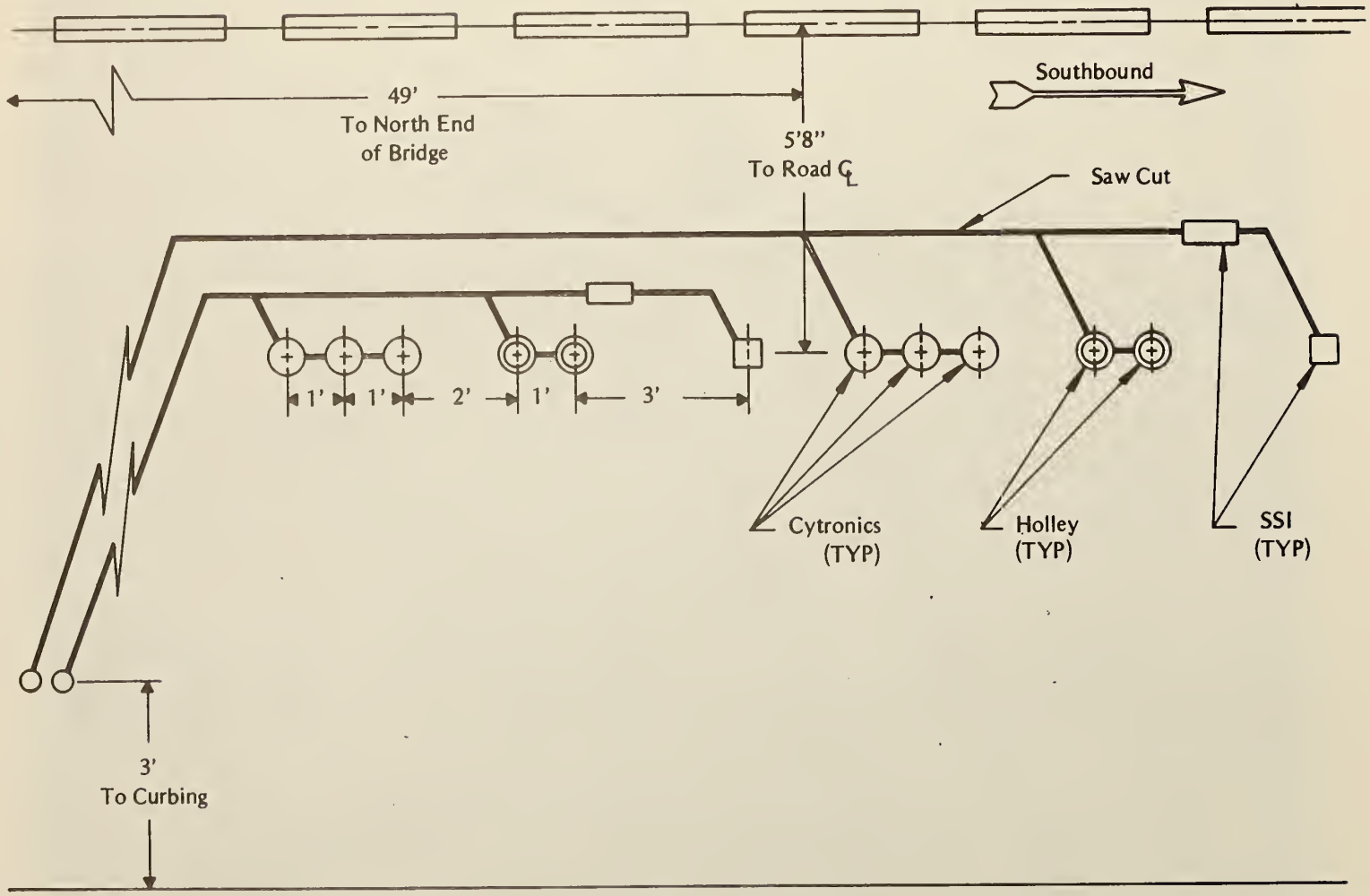


FIGURE 15
BRIDGE DECK SENSOR INSTALLATION

FIGURE 16
BRIDGE DECK SENSOR HEAD ARRAY

snow is present at the sides of the bridge. Two stipulations in the State Highway Encroachment Permit caused deviations to the normal installation procedures. First, the State would only permit through-deck holes to be drilled at either 3' 7" or 11 feet from the centerline of the road. To accommodate this requirement, shallow cores (approximately 3 inches deep) were drilled in the asphaltic concrete for the sensor heads and sawcuts were provided for the cables. The sawcuts lead to two through-deck holes located at 11 feet from the centerline. This can be seen in Figures 15 and 16.

The second stipulation was that the sensors be mounted at least 1/4-inch below the surface of the roadway. This requirement was imposed to insure that no contact would be made with the snow plow blades. The maintenance personnel in the severe environment area are justifiably sensitive to anything which could interfere with the snow removal operation. Thus, all the sensor heads were installed 1/4-inch below flush in violation of the vendors' instructions.

The complication introduced by that requirement is that snow, ice or water could accumulate in the depressions when, in fact, the bridge deck was clear. It was felt that these instances could be sorted out in the data analysis phase if the observer logged the actual condition of the sensor heads as well as that of the bridge deck. This policy was instituted.

Figures 17, 18 and 19 show the actual installation of the SSI, Holley and Cytronics bridge deck sensors respectively.

4.6.3 Traffic Measurement Stations

Magnatometers manufactured by Canoga Controls, Inc. were used for all traffic measurements. The parameters which were measured were speed at three stations, vehicle length and the presence of opposing traffic on the bridge.

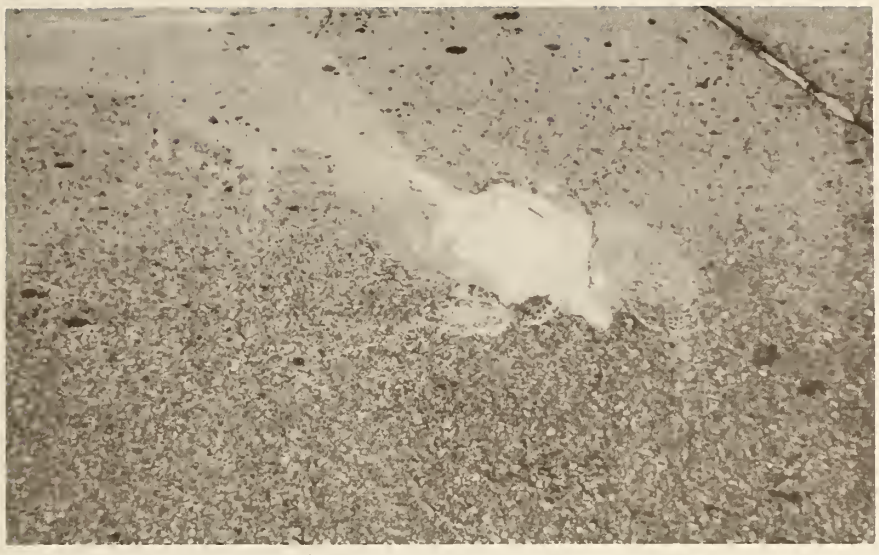


FIGURE 17
S. S. I.

FIGURE 18
HOLLEY

FIGURE 19
CYTRONICS

BRIDGE DECK SENSORS

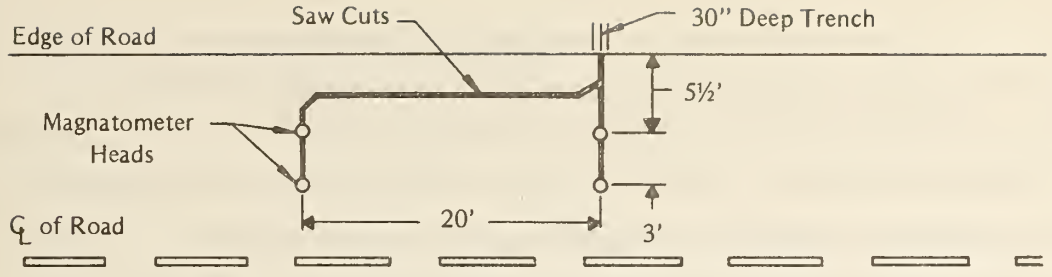
The speed stations were located at 1600 feet and 330 feet upstream from the bridge centerline. The third station was on the bridge at the centerline. Figure 20 shows the magnatometer arrays at each station.

Station One (1600 feet) consisted of two pairs of magnatometers located in the center of the southbound lane twenty feet apart. The heads were installed in drilled holes approximately 15 inches below the surface. The associated cabling was run in sawcuts to the edge of the road. All cuts and holes were then filled with epoxy.

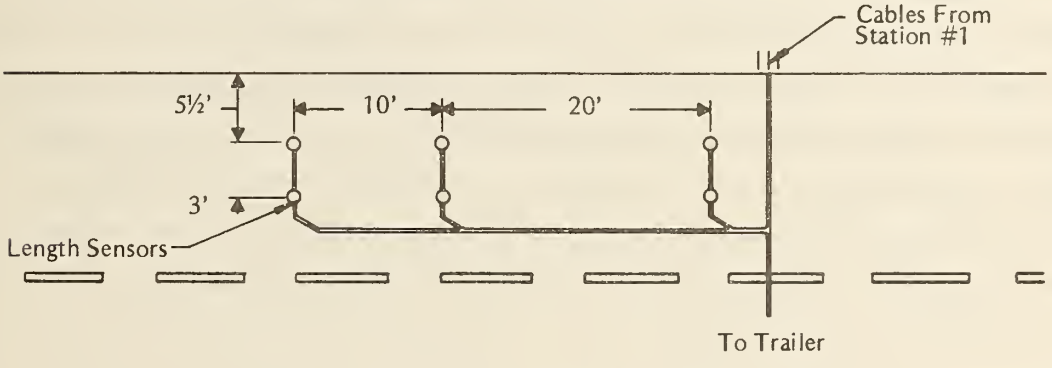
In operation, as a vehicle passed over the first pair of heads, an electrical pulse was generated and sent to the instrument trailer and amplified. The amplified signal is then sent to the computer at which time its real-time clock starts timing. When the vehicle reached the second pair, a signal would be sent which stops the clock giving an elapsed time to traverse twenty feet. The computer then calculates the speed.

Station Two (330 feet) has an identical speed measurement set-up (two pairs, twenty feet apart) but has an additional pair of heads ten feet downstream to measure vehicle length. In operation, speed is measured in the same manner as described above. The third pair measures the length of time that the vehicle was above them. With the speed just measured and the duration of presence, an approximate vehicle length could be calculated by the computer. The length measurement was only used to sort automobiles from trucks. Any vehicle calculated to be longer than 22 feet was arbitrarily classified as a truck.

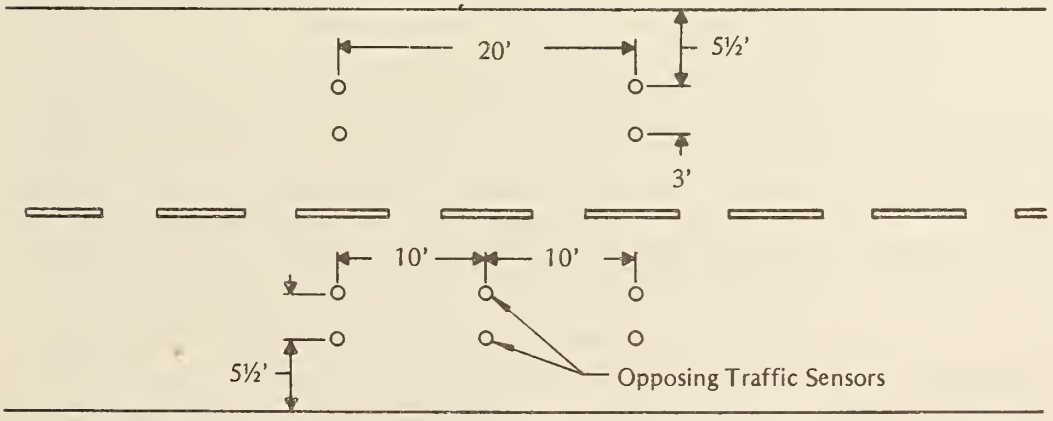
Station Three was located on the bridge itself. The magnatometer heads were epoxied to the underside of the bridge in this installation. Speed on the bridge was measured by two sets of four magnatometers covering both lanes. Opposing traffic was indicated by one pair in the northbound lane.



SPEED STATION 1
1600' from
Bridge ℄



SPEED AND LENGTH STATION 2
330' from
Bridge ℄



SPEED AND OPPOSING TRAFFIC STATION 3 ON BRIDGE CENTERLINE

FIGURE 20
TRAFFIC MEASUREMENT STATIONS

The requirement to extend the magnatometer coverage across both lanes arose due to the peculiar and unexpected behavior of southbound motorists during periods of heavy snow. As snow accumulates on the road during a storm, a plow is dispatched from the maintenance station located about five miles south of the bridge. The plow would clear the northbound lane for a distance of about 20 miles and then turn around to clear the southbound lane. For about two hours only the northbound lane is cleared at the bridge. It was found that southbound traffic would approach the test section driving in the correct lane and trigger the first speed station. As the vehicles came around the gentle curve between Station One and Two, they have an unobstructed view of the road for about a mile. In the meantime, they hit the second station and, if they can see no opposing traffic, they immediately pull out and drive on the cleared opposite lane. They would thus miss southbound lane instrumentation on the bridge. Both lanes were therefore instrumented. The computer, however, was programmed to accept only southbound traffic.

The opposing traffic sensors were located on the northbound lane. If a vehicle triggered the northbound sensors while a southbound vehicle was between Stations Two and Three, the presence of opposing traffic was noted.

4.7 Site Operation

Data from the installation was collected and recorded and preliminarily reduced automatically. However, an observer was on-site for four hours each day (seven days a week) from 0400 to 0800 hours to personally witness the condition of the bridge and to assist in the traffic study. The duties of the observer and the format and philosophy of the automatic data collection scheme will be discussed in this section.

4.7.1 Observer Duties

The primary duties of the observer were:

a. To observe the condition of the bridge deck.

b. To count the number of vehicles which applied brakes on or near the bridge during his watch.

c. To resupply the teletype with paper and punch tape.

d. To ship the data to MBA's San Ramon plant on a weekly basis.

MBA was very fortunate in hiring a local observer who was extremely competent and conscientious. In addition to being very responsible, he also had a knowledge of both computers and electronics. While his duties as an observer were quite straightforward, his skills were found to be invaluable in troubleshooting the system and debugging the program. This saved numerous trips from San Ramon to the test site (approximately 190 miles), since many problems could be solved by a telephone call to the observer during his watch.

The observer began his routine at about 0400 each morning by going down to the bridge deck to observe its condition and that of the detector heads. At the bridge, he would key a switch located on the bridge railing. Upon receipt of that signal, the computer would print the time of the observation. He would then return to the trailer and make appropriate entries on the teletype keyboard. Using a two-digit code, he would record general bridge deck condition, his observations of the weather and the condition of each sensor head. During the course of his watch, a tour to the bridge would be made at about 40-minute intervals.

His primary duty in the trailer was to count the vehicles which passed and note those which applied brakes on or near the bridge. When a vehicle passed the first station, an audible alarm would sound to alert the observer of an approaching vehicle. He would then move to his observation position and push one of two buttons for brake lights or

no brake lights. The computer would store the entries and at the end of the watch, the observer would interrogate the computer by pushing an appropriate key on the keyboard. The system would then print the total number of vehicles observed and the number that applied brakes.

4.7.2 Automatic Data System

Figure 21 is an illustrative printout which was prepared to show all of the data types which were recorded. It would be useful to refer to this figure as the elements are described in the text.

Referring to Figure 21, it can be seen that there are nine general data types recorded by the system. The first type at the top of the page is the indication given if a power failure occurs during automatic operation. The system will automatically restart when the power is restored but the real-time clock will be off by however long the power was down. The program must be restarted using the correct time and date to restore the system to normal operation. The second data type is the indication that the program was restarted and initialized by the observer at 0625 on 4 January.

The third data type is a result of input from the observer. The time is printed when the observer is inspecting the bridge and keys the switch on the bridge railing. The time indicates when a personal observation was made.

The set of data shown in four is also observer input. When he returns to the trailer from his tour, he enters the condition of the bridge deck and his observation of the general weather conditions. The first entry in the set indicates that there was snow on the bridge deck and it was snowing at the time. For the bridge deck condition, the observer could select any of seven conditions using a one-digit code. These were dry, clear, wet, slush, frost, ice, or snow. To describe the general weather, there were also seven conditions from which to choose: clear, cloudy, fog, sleet, rain, snow, or blizzard.

```
!POWER FAIL AT 2300                                          (1)

HR:MIN MON/DAY
06:25 01/04                                                  (2)

?0629                                                        (3)

@0631#0001T G9 SP 68 56 55 N

&0632 SNW SNW
&0634 S1= SNW
&0634 S2= SNW
&0634 H1= SNW
&0634 H2= SNW                                                (4)
&0634 C1= SNW
&0634 C2= SNW
&0634 M1= SNW
&0634 M2= SNW

@0636#0002T G9 SP 50 47 48 N

*0649 H1=ICY
  AIR BRD ROO DEW  WNO  PRE ILL
5 09' 12' 22' 08' 000 262 Y 01
4 09' 12' 22' 08' 000 262 Y 01                               (5)
3 09' 12' 22' 08' 000 262 Y 01
2 09' 12' 22' 08' 000 262 Y 01
1 09' 12' 22' 08' 000 259 Y 01

:01-04 0650
 S1=ICY S2=DRY H1=ICY H2=DRY C1=ORY C2=ICY M1=ORY M2=DRY     (6)
 AIR 09'BRD 12'ROO 22'DEW 08'WNO 000MPH 262'PRE Y ILL 01

@0655#0003T G9 SP 62 57 60 N

@0701#0004C G9 SP 50 51 52 N

@0704#0005C G9 SP 50 45 49 Y

@0705#0006C G4 SP 60 55 58 Y

:01-04 0710
 S1=ICY S2=ORY H1=ICY H2=ORY C1=ORY C2=ICY M1=ORY M2=ORY
 AIR 09'BRO 12'ROO 22'OEW 09'WND 000MPH 255'PRE N ILL 01

>0711 H1=ORY                                                 (7)

@0718#0007C G9 SP 47 43 47 N

:01-04 0730
 S1=ICY S2=ORY H1=DRY H2=ORY C1=DRY C2=ICY M1=ORY M2=ORY
 AIR 11'BRO 13'ROO 23'OEW 09'WNO 000MPH 252'PRE N ILL 02

?0744

@0744#0008T G9 SP 65 61 68 Y                                 (8)

@0745#0009C G9 SP 56 50 56 N

@0745#0010C G3 SP 60 55 54 N

@0745#0011T G6 SP 54 32 51 N

$0746#11 03                                                  (9)

&0747 SNW COY

&0747 S1= SNW
```

FIGURE 21
ILLUSTRATIVE COMPUTER PRINTOUT

The next eight entries in data set four indicate the actual condition of each sensor head. The first entry indicates that the observer actually saw snow in SSI #1 sensor head. H1 and H2 refer to Holley #1 and #2 systems, C1 and C2 refer to the Cytronics units and M1 and M2 refer to the modified Holley units. To specify sensor head conditions, the observer may select any of the seven conditions listed in the prior paragraph.

Data set five shows a sensor status change. This shows that a 0649, Holley unit #1 went to the ice condition. The information printed following that entry is weather data for the five minutes immediately preceding the change. The last line in that group is the weather for the minute preceding the change. It reads: minute #1, air temperature 9°F, bridge deck temperature 12°F, road temperature 22°F, dew point 8°F, wind speed 0 mph, wind direction 259° (in this case with zero wind velocity, 259° is the direction from which the wind last came), precipitation - yes, illumination level 01. Illumination level was given on a logrithmic scale from one to ten to approximately correspond to the human eye. 01 is very dark and 10 would be very bright.

Data type six is a routine 20-minute weather and sensor status report. It begins with the date and time of the report (in this case, 4 January, 0650). The status of each sensor is printed and then the weather as described above. This report is made routinely at 20-minute intervals regardless of sensor activity.

Data type seven is another type of sensor status change. This is similar to type five except it occurred within five minutes after a weather report. In this case, weather data for the last five minutes is not printed. This feature was incorporated to prevent excessive weather printouts in the event of a cycling sensor.

Data types eight and nine deal with traffic information. Data type eight is a typical speed report. It can be seen that at 0744 vehicle number eight passed by. This letter T indicates that it was longer than 22 feet and therefore classified as a truck. It arrived at

least nine seconds after the previous car. The speed at Station One was 65 mph, at Two 61 mph, and at Three 68 mph. The letter Y indicates that there was opposing traffic on the bridge. At 0745, vehicle number nine passed by. It was a car and had no opposing traffic. Vehicle ten was also a car and had a three-second headway (G3). The data for each vehicle is printed out immediately after the vehicle clears the Number Three station.

The vehicle number is assigned at the first station. They are numbered consecutively from midnight to midnight and then the count starts again with #1. Whenever the program is restarted or reentered, the count also reverts to #1, regardless of the time.

The final data type (number nine) is a summary of the brake light observations. As mentioned previously, the observer has to key brakes or no brakes for each car passing during his watch. Prior to leaving, he makes a keyboard entry and the computer responds with the time (0746), the total number of cars observed (11), and the number that applied brakes (3).

4.8 Weather Conditions

The Prosser Creek test site proved exceptionally suitable for the conduct of an experiment that required adverse weather conditions. The data presented herein represents a summary of the weather data at the National Weather Service Station at Truckee, California, located five miles south of the test site. When the data from the site is finally reduced, some minor changes will be noted. It has been noted that the temperature swing at Prosser Creek is somewhat greater than that at Truckee. Also, the mean daily minimum temperature tends to be about 4°F lower than at Truckee.

During an 181-day period from November 1973 through April 1974, snow fell of 59 days and during these storms chains were required on 38 separate occasions. The total precipitation during the period was 29.23 inches. The total snowfall was 210.3 inches. During the period of 181 days, the temperature passed through freeze-thaw on 141 days.

Table 3 summarizes the weather on a month-by-month basis. From this weather data, it can be seen that this location provides excellent conditions for experiments which require high frequency of severe weather events.

4.9 Detector Performance

Generally speaking, the detector performance was most disappointing. Throughout the winter period, the systems were plagued with a myriad of problems that arose from component failures and faulty adjustment and calibration. The difficulties experienced during the season are presented chronologically.

December 1973

After installation in accordance with the manufacturers instructions, all systems were energized with the following results:

- One Cytronics unit failed immediately, due to a faulty component.
- After about two weeks of operation, one of the Holley heads failed rendering one unit inoperative.
- Both SSI units operated but did not faithfully track the bridge deck conditions.

The vendors were then contacted for spare parts and more comprehensive checkout information. They were also told that a visit would be necessary if the checkout and alignment instructions did not remedy the problems.

January 1974

More detailed tune-up procedures were carried out on the Cytronics and SSI controllers. The one Holley system which was on line appeared to be working up to capability, thus no adjustments were made.

TABLE 3

National Weather Service Station
Truckee, California
(5 miles south of Prosser Creek Bridge)

	Nov. 73	Dec 73	Jan 74	Feb 74	Mar 74	Apr 74
Mean Daily High Temperature (°F)	42.8	37.8	35.7	40.3	45.3	50.2
Mean Daily Low Temperature (°F)	24.9	18.1	14.8	11.1	22.0	22.8
Total Precipitation (in.)	7.51	6.21	5.01	2.11	6.71	1.68
Total Snowfall (in.)	31.8	55	29.5	29.5	48	16.5
# of Days with Snowfall	10	9	9	10	11	9

Several more sensor failures were located during the period. One of the Cytronics heads was found to be damaged apparently due to an impact of a tire chain. After a period of questionable operation, a check showed that two more Holley deck sensors had failed, thus rendering both units inoperative. Replacement heads were requested from both Cytronics and Holley. These heads were received late in the test period.

The detailed tune-up procedure on the Cytronics and SSI units did not significantly improve performance; thus, technical representation was requested. Members of the staff of Cytronics and SSI visited the site during the week of 14 January 1975. At that time, one of the Cytronics units was found to have a faulty printed circuit board. This was returned for repair, leaving one Cytronics unit down. The SSI representative added a modification package to each controller. The modification changed the current to the conductance plate from D. C. to A. C. which should eliminate plate shorting.

February 1974

Replacement heads for the Holley and Cytronics units were installed on the bridge. The repaired Cytronics printed circuit boards were also installed.

Upon removal of the failed Holley heads, it was found that the cause of failure was a breakdown of the insulation on the heater wires. Since the replacements were identical, additional failures were expected and in fact occurred. The vendor was notified and began to prepare new heads with improved insulation. The Holley P. C. boards were also returned for checkout.

With the repaired P. C. board and replacement head, the Cytronic units continued to perform poorly. At the vendor's request, both controllers were returned for check-out.

The SSI units were also performing poorly. This prompted the SSI technical representative to visit the site and make an additional modification to both controllers.

March 1974

The second set of Holley heads, with improved insulation, was received and installed. The units were recalibrated late in the month using vendor equipment.

The Cytronics controllers were repaired, returned to the site and installed late in the month.

The SSI equipment continued to perform erratically. The SSI technical representative visited the site for the third time to diagnose the behavior. The difficulty on one unit was traced to a faulty in-line amplifier installed in the bridge deck. A replacement unit was ordered.

April 1974

The SSI -in-line amplifier was replaced on 4 April 1974. This replacement ostensibly placed all six units on the line, currently calibrated and adjusted. The units were run for the duration of April essentially unattended without additional modification, calibration or adjustment. During this period one Holley and one SSI unit apparently failed since no status changes were received after the first several days of the period. The remaining four units functioned electrically throughout the period with varying results.

The Holley unit that remained on the line throughout the period showed the best overall performance. During the period, the device went to either "ice" or "alert" status a total of 12 times. Of these, three were considered to be false alarms and nine were proper responses. It appears as though there were no "missed" events. The three false alarms were in the frost prediction mode. It appears that this function tends to react somewhat too early as the conditions approach those necessary for frost formation.

On those events during which the device responded correctly, several times the reaction came up to one hour after the onset of the event. No explanation is currently available for this phenomenon.

The performance of the SSI unit that functioned throughout the period was less satisfactory. It went to "alert" or "ice" status eleven times, only two of which could be associated with an event. Alarms on five confirmed events were missed.

Both Cytronics units functioned throughout the period but cycled between "clear" and "ice" almost continuously, apparently without regard to the actual weather conditions. Discussions with the manufacturer near the end of the period indicated that they were experiencing identical problems with their test unit in their laboratory. This indicates a problem in the controller circuit. The manufacturer is aware of this and is working toward a solution.

4.10 Traffic Performance

MBA selected four periods for preliminary speed analysis as an illustration for the 1973 - 1974 winter test period. The major conclusions are as follows:

1. Vehicles slow down in bad weather (snow storms, e.g.). However, some of this behavior may be a result of the imposition of chain controls rather than a result of driver response to his perception of the hazard.

2. In April, trucks drove slightly faster than cars through the first speed trap. The difference has not yet been proved significant at the second speed trap. This, of course, is a measurement of the behavior of those truck and car drivers who traveled this particular road.

3. It was not possible to detect any effect on speed due to illumination level (night versus day) or due to presence of frost on the bridge.

4.10.1 Two Snow Events

During the observing season from 15 December 1973 to 30 April 1974, at least 20 storms occurred that were severe enough to require chains on the stretch of highway that included the instrumented

bridge. At random, MBA has selected two of these storms for illustration here. Of course, there were many other snow events that were not sufficiently severe to warrant legal chain requirements, although they did place snow and ice on the bridge.

Figure 22 is a carriage plot showing the speeds of vehicles across MBA's instrumented speed measuring array. The abscissa plots car number. The time gap between neighboring car arrivals is different for each pair of cars, but this difference is not graphically shown here. The figure shows vehicle speed spanning the New Year's Eve blizzard. Approximately 87 cars are recorded over the 24-hour period from noon December 31 to noon January 1. The ordinate indicates the vehicle speed on a scale from zero miles per hour to 100 miles per hour. For each car, three symbols are printed, one for the speed at each of the three speed traps. The symbols cannot be resolved at the above level of reduction, and differences between the speeds across the traps is not the major point of this figure anyway. According to MBA's observer, the storm started at around 0700 on December 31. This is corroborated by precipitation records at the National Weather Service observing station in Truckee. It was snowing at 1100 when MBA's observer revisited the site after leaving at the end of his morning watch. Chain controls were imposed by the State maintenance personnel at 1715 on December 31. These controls remained in effect until 0748 the following morning. MBA's observer had indicated that it had stopped snowing at the instrumented bridge sometime between 0400 and 0500. Presumably, snowfall was more or less continuous between 1100 on December 31 and January 1, although MBA's observer was not present and left no such record.

Inspection of Figure 22 shows a dramatic drop in speed during the period in which chain controls are in effect. This may reflect general driver caution on hazardous roads during a blizzard, but it may also be mainly caused by the fact that vehicles with chains are a nuisance to drive at high speeds because of the chains knocking against the fenders. The figure shows that drivers

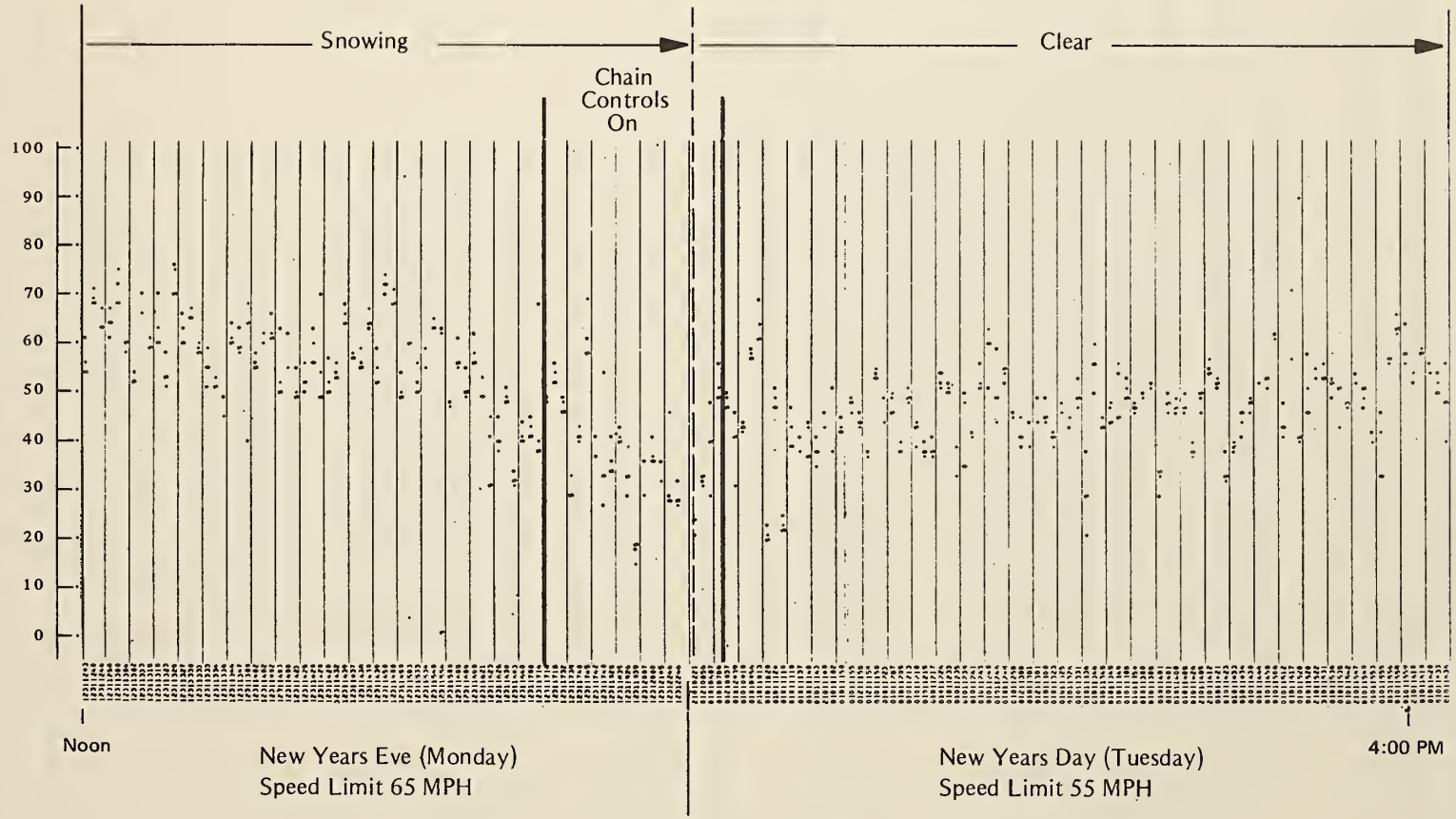


FIGURE 22
VEHICLE SPEEDS THROUGH NEW YEARS EVE STORM

anticipate chain controls. Speeds began to decline two hours before controls were imposed. Note that the effect of the new speed laws was to reduce speeds on New Year's Day to levels consistent with the new 55 mph speed limit.

Figure 23 shows statistics on traffic during the snow storm that occurred during the 24-hour period between noon February 28 and noon March 1, 1974. Eighty-one vehicles passed the speed array during that period. Out of the total number of vehicles, there were 53 cars. Figure 23 shows the average speed and the number of cars in the sample for each of seven periods that span the 24 hours. In Figure 23, the abscissa is time. The seven periods represent different combinations of the following three factors: illumination level (day versus night), precipitation state, and chain controls. Because the sample size was so small for each period, the only statistically significant differences between neighboring periods turned out to be between periods 2 and 3, and between periods 5 and 6. That is, speeds during the chain control period were significantly different from those when chains were not imposed. This conclusion can be stated with 95 percent confidence. It was reached by applying the standard statistical test to the means of two samples of different size and different standard deviation. Note that Figure 23 suggests that driver behavior anticipates chain control severity by about 2 hours.

4.10.2 Other Speed Statistics

Table 4 shows statistics for about 459 vehicles that crossed the speed array between December 22 and January 2. About half the vehicle measurements were taken in what could be called good weather, and half in bad weather. The snow storm of Figure 22 was included in this period.

Table 4 shows a statistically significant difference in speed between good weather and bad weather. Also, the table suggests that each individual driver is likely to slow down slightly before approaching the bridge, and then return to normal speed while he is on the bridge.

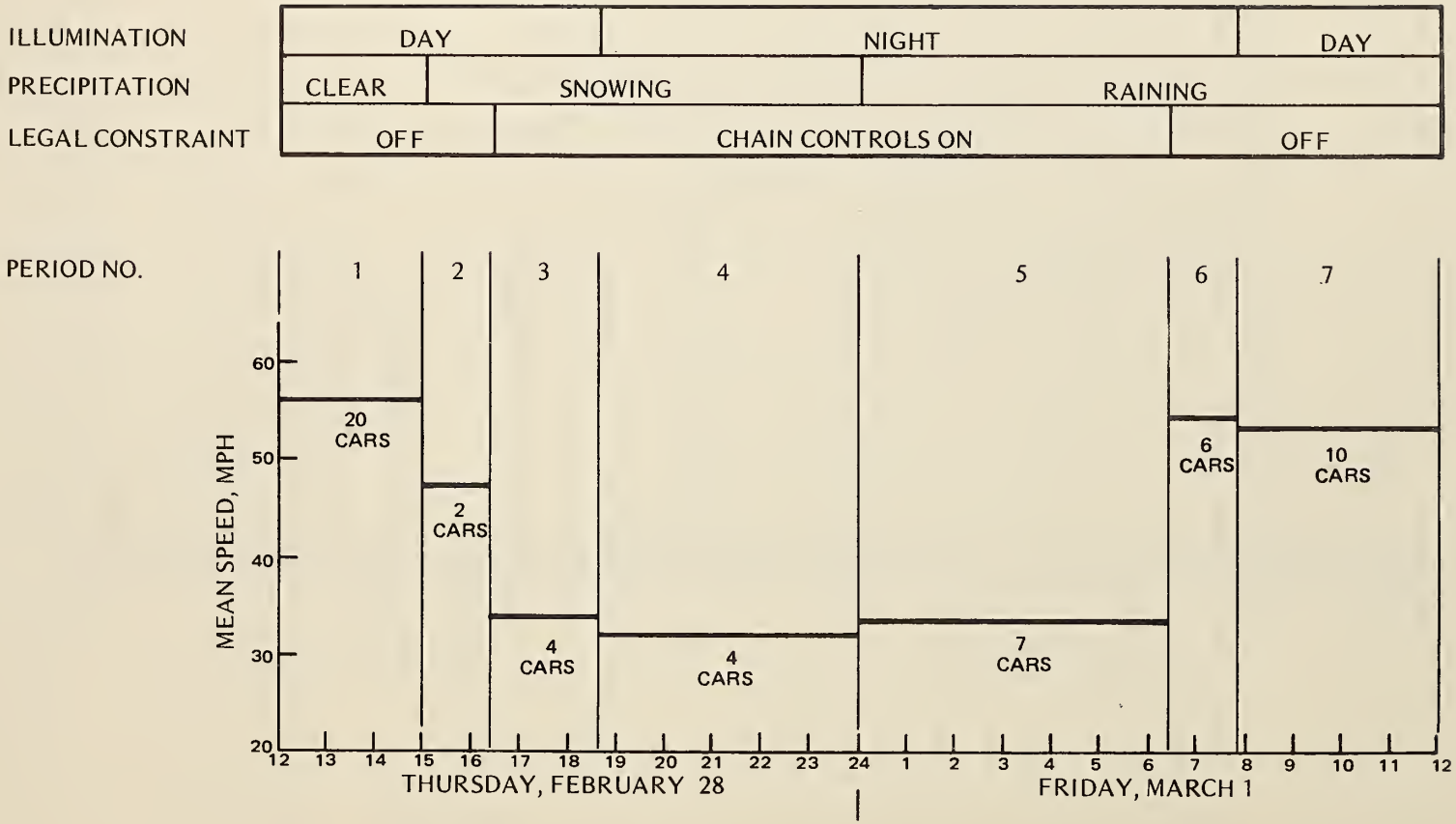


FIGURE 23
MEAN SPEEDS SPANNING FEBRUARY 28 STORM

TABLE 4

SPEED STATISTICS, VEHICLES
December 22 - January 2

Speed, or Speed Difference	All Weather		Good Weather		Bad Weather	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
T1	55.0	11.9	61.1	7.9	47.8	10.4
T2	52.0	10.6	57.5	7.7	45.3	9.1
T3	54.4	11.6	60.7	8.2	47.0	9.7
T1-T2	+3.0	8.4	+3.5	6.3	+2.4	6.4
T1-T3	+0.6	9.3	+0.4	6.6	+0.8	7.3
T2-T3	-2.4	6.3	-3.1	4.6	-1.7	4.5
n	459		250		203	

The difference in means between speeds at traps one and two are significant. The difference between speeds at traps two and three are significant. The difference in speed between traps one and three cannot be said to be significant. These conclusions are reached with 95 percent confidence.

Table 5 presents speed statistics on two days in April 1974. April 15 was taken as a clear day, and thus its speed data might be considered the nominal good condition statistics. On April 25, the MBA observer noted frost on the bridge in the vicinity of the snow and ice detector array and accordingly, April 25 was taken as representative of a frosty day when the conditions were otherwise normal. The frost condition may have begun around midnight. It was actually seen there by the MBA observer when he arrived at the facility around 0400. The observer still reported frost at 0750 when he was about to leave the facility. The "MBA Frost Detector Number 1" reported frost until 0825. About half the vehicles in the frost sample went through in darkness or at dawn, and half went through in full daylight.

Some of the conclusions that can be reached with 95 percent confidence using the Student test are as follows:

1. On April 15, trucks were traveling faster through Trap 1 than cars.

2. The same conclusions about vehicle speed differences between Traps 1 and 2, 2 and 3, and 1 and 3 that were drawn from Table 1 are also supported by the April 15 data. Both cars and trucks exhibit this behavior.

3. Vehicle speeds through Traps 2 and 3 were not significantly different when frost was on the bridge as compared to clear conditions.

4. Vehicle speeds at day and at night are not significantly different.

TABLE 5

VEHICLE SPEED STATISTICS
ON A CLEAR DAY AND A FROSTY DAY IN
APRIL 1974

Date	Illum. Level	Frost or Clear	Vehicle Class	Trap	$\bar{X}$	S	n
4/16 (Tuesday)	Day	Clear	Car	1	59.3	9.23	89
				2	56.6	9.10	
				3	58.6	9.21	
			Truck	1	62.53	8.37	49
				2	57.4	7.57	
				3	59.5	10.15	
	Night	Clear	Car	1	60.5	7.54	35
				2	57.8	7.53	
				3	60.5	8.53	
			Truck	1	65.2	8.38	25
				2	58.3	5.74	
				3	61.4	7.07	
4/25 (Thursday)	Night, then Day	Frost	Car	1	63.4	7.10	14
				2	57.6	9.90	
				3	59.4	9.31	
			Truck	1	65.1	8.16	10
				2	58.8	5.20	
				3	60.20	5.25	
	Day	Clear	Car	1	61.2	6.61	64
				2	58.1	7.29	
				3	60.2	8.02	
			Truck	1	62.5	6.26	55
				2	58.5	7.68	
				3	60.4	6.92	

Note: On both days, the total traffic southbound was 180 - 210 vehicles.

It is interesting to ask why speeds across Trap 2 should be lower than those across Traps 1 and 3. Conjecture one would be that the vehicles slowed down slightly as a precaution while passing the Hobart Mills intersection to the left. Conjecture two is that a driver approaching the Prosser Creek bridge sees the bridge as a small target and slows down somewhat to assure himself adequate control while crossing. Once on the bridge safely, the driver must feel free to speed up. Prosser Creek bridge is not what would be called a high design bridge since it does not have wide shoulders, and the approach has not been elaborately landscaped to mask the visual disparity in width between road and bridge.

All the information on the February, March and April days was for cars that were free to choose their own speeds (were not in the car following mode). Also, the vehicles encountered no opposing traffic on the bridge. This latter element of freedom allowed many drivers to cross the bridge straddling the median, especially when snow had been piled on the curbs by the railings.

5.0 PHASE II - SECOND YEAR TESTING

Phase II, conducted during the second year of the Snow and Ice Detection and Warning Systems Project was initiated by a summer, laboratory testing effort and development of a data storage program for the collected information processed by the Nova 1210 mini-computer system. Following the completion of the summer of activities, the Prosser Creek field site was reactivated in late October 1974. Initial second year testing officially started on November 1, 1974. The second year of sensor testing was culminated in a four-week motorist warning system test during March and April 1975. Although the activated motorist warning signs had to be manually operated due to lack of snow and ice sensor system reliability, the test conditions provided fourteen separate occurrences of hazardous bridge events. These events under twenty-four hour surveillance provided a data base for:

- Evaluation of Snow and Ice Sensor System event detectability and false alarm rate.
- Evaluation of the Motorist Warning System impact on vehicular speeds.

5.1 Data Storage Program and Summer Testing of Sensor Systems

During the summer months of 1974, programs for packing the Nova gathered data onto magnetic tape storage and a Laboratory Testing Program for the Snow and Ice Sensor Systems were developed.

The Nova driven data acquisition system produces real time information on a teletype and punched paper tape. The information from these tapes was transferred to magnetic tape. The magnetic tapes were then stored in Control Data Corporation's, CDC's, Cybernet Center located in Palo Alto, California. The CDC Cybernet Center is a centrally located computer facility possessing two CDC 6600 computing systems. Access to these computers is via remote terminal facilities with telephone line communications. MBA maintains a CDC MARC II Facility at its San Ramon Corporate office. This facility is shown in

Figure 24. Conversion and storage of the remote site data made the vast data base generated during the field tests available for further analysis using the CDC 6600 computer systems.

The summer laboratory testing program was concentrated around the Holley and SSI systems. No descriptive, detailed information was received on the Cytronics System until the very end of the test period. It was clear from the initial year of testing that the Cytronics sensor system had very limited capabilities with respect to snow and ice detection. Frost conditions were rare at the test site so little was known about the Cytronics frost detection capability. MBA was provided with detailed circuit diagrams relative to the Holley system. Information provided on the SSI system was also limited due to propriety of the system. The degree of test emphasis given to each system was in direct relation to the amount of information received.

5.1.1 Data Transfer and Storage Program

The data processing unit consisted of the varous peripheral sensors, the NOVA 1200 Computer, program SNONICE (Volume II), and the ASR 33 Teletypewriter. The ASR 33 Teletypewriter produced a man-readable printed as well as an 8-track punched paper tape of all data. Since punched paper tape is an extremely slow Input/Output medium and is incompatible with processing on the CDC 6600 time-share system, it was necessary to transfer the punched paper tape data onto magnetic tape.

To do this task an in-house program was written in FORTRAN IV and COMPASS (CDC Assembly Language) to pack the paper tape punch data onto magnetic tape. The data was packed by type of report, e.g. twenty-minute report, detector status change and associated five minute weather report.

With the data converted into usable code, analysis programs could be written which only required searching for certain signal character bits and then unpacking the desired data. Programs also checked for nonsense words and cycling or repeating data since the data conversion process only duplicated the original paper tape into CDC 6600 and computer programmer usable form.

FIGURE 24
MBA'S TERMINAL FACILITY CDC MARC II

5.1.2 Sensor Laboratory Testing Program

April 1974 field test results had revealed improvement in the snow and ice sensor system operation, particularly for the Holley System. A summer 1974 test was initiated to improve the sensor system reliability.

The depth to which the testing program was conducted was based upon the degree to which the sensor manufacturers were willing to supply detailed system design and functional information.

In the case of the Cytronics system all system information was withheld until the end of the test program and only then a minimal amount of information transmitted. The proprietary nature of the Cytronics system was the reason given for the lack of manufacturer supplied information. SSI cooperated to a greater extent than Cytronics in supplying system functional information. Again, however, due to proprietary information, no detailed circuit diagrams were received by MBA for the summer test program.

The situation was different in the case of the Holley unit where detailed circuit diagrams were received. The primary reason for receiving the detailed information was the fact that the manufacture of the Holley system was discontinued. The rights to the Holley system now belong to Meteorology Research, Inc. who have expressed interest in improving and marketing the Holley system.

5.1.2.1 System Modifications

A few modifications were made to each system as a result of the winter testing. Based upon temperature and humidity (T&H) chamber testing of all three system controllers it was found that low temperature affected the outputs of the controllers. Therefore thermostatically controlled strip heaters were installed in all controllers for the second winter of testing.

The remaining modifications were restricted to the Holley units. One modification concerned replacement of heavy duty mercury relays since these were found to stick frequently. This caused

the system output to "lock up" into a mode regardless of the input. Replacement was by mechanical types which exhibit superior performance. The second major modification was augmentation of the frost prediction feature. It was recognized by MBA personnel that if this function were accurate, then an additional condition imposed by checking conductivity of the unheated head would lead to either a decision of no conductivity, frost, or conductivity which implied cold dew. Analysis of the remaining circuitry revealed that the design as well as component selection could be improved. This, however, was not considered to be within the project scope and any effort to replace certain components or circuitry selectively would not be warranted without conducting an entire system analysis.

Results of the calibration testing are presented in the succeeding section

5.1.2.2 System Testing

Each of the systems was calibrated in the laboratory during the summer between the two winter field periods. The details of the calibration test procedures are presented in Appendix B. These results are summarized below.

- Cytronics System

Thermal sensitivity and temperature and humidity chamber tests were performed on this system. These revealed controller sensitivity at low temperatures and under controlled environmental conditions the sensor head performance was unpredictable. Due to a lack of detailed information on the system, little interpretation of the inconsistent results could be made.

- SSI System

Sensor head tests were made using salt solutions, ice and slush. Environmental tests were also made in the T&H chamber. These tests were conducted against both manufacturer recommended

and MBA developed values for dry alarm, wet alarm, and ice alarm conditions. Errors were detected in the alarm threshold temperature values and corrected accordingly.

- Holley System

Since MBA was provided with detailed schematics, calibration procedures, and an operation manual for the Holley system, a complete and thorough calibration of the system was possible. MBA further developed an independent calibration procedure. Air temperature thermistor, conductivity, and T&H chamber tests were conducted. Salt, ice, and slush conditions were also tested. A discrepancy between the two Holley units was discovered and corrected, and a complete set of calibration curves was developed. Based on this comprehensive calibration test and evaluation effort, MBA was able to create a frost detection modification to the Holley unit. This was accomplished by adding a simple logic element that checked the conductivity of the unheated sensor head whenever the system entered the anticipatory mode. If the unheated head was conductive, the conclusion was that there was cold dew present and if it was non-conductive, frost was present.

5.2 Restart of Winter Testing

The Prosser Creek test site was restored to operation during the latter two weeks of October 1974. The instrumentation trailer was again located and all equipment reinstalled in the trailer. The roadway sensor controllers were returned to their location under the bridge. The weather station was calibrated with the dew cell and ambient temperature device and the latter two devices located on the west side of the bridge, rather than adjacent to the trailer as in the first winter's test.

The bridge sensor heads were removed and calibrated. New replacement heads for one Holley system and both SSI system were reinstalled in the bridge deck. MBA personnel were joined by representatives from both Cytronics and SSI during the removal, calibration and installation phase.

Some new Nova programming modifications were made for the second year of testing. A check of speed trap accuracy was made using a fifth wheel, as well as a California Highway Patrol vehicle.

5.2.1 Nova Programming Modifications

There were several major modifications to program SNONICE (see Volume II) between year 1 and year 2 of the data collection. In addition, a couple of minor adjustments were made to subroutines in order to process additional observer input and to eliminate cycling of the output data.

One of the major modifications was the manipulation of ASR 33 Teletypewriter. It was found in Phase I that the teletypewriter was a very sensitive piece of equipment and its breakdown was a major cause of downtime during the winter of 1973-1974. The breakdowns were attributed to the fact that the teletypewriter was running continuously for 24 hours a day. This problem was solved by turning the power on to the teletype when there was data on the output buffer and off otherwise. This meant determining if there was a need for output in the Teletype Output Service Routine, determining if the teletype required power in the Executive Routine, turning the teletype power on or off in the General Utility Subroutines, and finally printing the character in the output buffer using the Teletype Output Service Routine.

A few detectors were eliminated in the study for Phase II. This changed the analog input word since it had less bits. Therefore, the routines for processing the detector status had to be altered as well as printing the twenty-minute report and detector status. The display of the detectors' status on the NOVA display console also required change and the General Utility Subroutines shortened the bits for detector status and reallocated them to displaying the teletypewriter status. Observer input of the status of the detectors also had to be changed since there were fewer of them. The Teletype Input Service Routine also added the ability to indicate the road condition by printing "ROAD CONDITION" followed by the time status and weather status.

The first year problem of repeating a buffer length's output, cycling, was resolved by requiring more control of the pointers to the output buffer in the Teletype Output Service Routine and the various tables of weather, car, and detector data.

The NOVA 1200 program is detailed in Volume II of this report.

5.2.2 Speed Trap Calibration

A fifth wheel was used to calibrate the speed traps at the Prosser Creek test site. The wheel itself was calibrated at forty-five (45) miles per hour. This was done by a sequence of successive runs over a measured mile. By endeavoring to hold a constant speed and verification of this speed through stopwatch timing of the trip time, it was possible to determine the voltage output of the wheel at 45 miles per hour. Based upon a number of such runs over the measured mile it was determined that the fifth wheel was accurate to approximately .2 mph at 45 mph.

This wheel was then transported to the Prosser Creek test site. A voltage meter modified to read miles per hour was used as the output for speed readings. Approximately fifteen test runs between 44 and 46 mph were made over the three speed traps. In all instances the trap #1 computer output speed was consistent with the fifth wheel. These repetitive runs also indicated that traps #2 and #3 were between 1.0 and 1.5 mph higher than the fifth wheel. This corresponds to an effective trap distance of approximately 19.5 feet instead of 20 feet. This error corresponds to vehicles of length 21.45 feet or greater being given truck classification rather than 22 feet.

Since a single routine in the Nova computer program calculates speed for all 3 traps, the computer adjustment for trap 2 and 3 effective distances would require an additional routine for traps #2 and #3. It would also require that any data analysis of the initial year testing would take into account this correction factor. Rather than instituting a correction for the second year, it was decided to leave the traps as they were during the first year. It was reasoned that being cognizant of this error was the only importance. Any data analysis relative to comparison of actual trap speed differentials where the error would alter conclusions would require adjustment in observed verus actual speeds. Subsequent analyses revealed no cases where the error was so significant.

5.3 Motorist Warning System

Task F of the Snow and Ice project called for design and implementation of a motorist warning system. Activation and control of the warning system was to be based upon the output of the most promising of the snow and ice sensor systems tested at the Prosser Creek site.

The purposes of the motorist warning system test can be considered as threefold:

- Design and implement a functional system
- Evaluate how well the system performed from the standpoint of equipment reliability
- Evaluate the motorist response to the warning system.

Based upon the possible ramifications associated with transmission of incorrect information (false activation) or failure to transmit correct information (failure to activate) together with past performance characteristics of the ice and snow sensors it was decided to conduct the motorist warning system test in a manual operational mode. The basic test purposes could still be achieved under manual operation by comparison of what would have happened had any of the sensor systems directly or indirectly (by collective logic) controlled the motorist warning system.

5.3.1 Sign Selection and Location

A Federal Highway contract no. DOT-FH-11-7972 entitled "Driver Awareness of Highway Sites with High Skid Accident Potential" (Reference 1), was reported by its principal investigator Mr. Fred Hanscom of Biotechnology, Inc. in July 1974. One of the driver responses studied by the subject report related to the potential skidding hazard of a preferentially iced bridge deck surface. The local weather conditions at the Prosser Creek Bridge can produce a skidding

hazard, conjunctive upon, or preferential to, either the bridge or approach roadway surfaces. This skidding hazard can be frost, snow pack, slush or general ice.

It can be argued that the hazard message transmitted to State Route 89 motorists approaching the Prosser Creek Bridge can be improved upon relative to the sign messages tested in the previously referenced DOT/FHWA project. However, it is likely that the activation feature of the motorist warning signs is more significant than the message content of these signs. Therefore, so as to utilize the results of the DOT-FH-11-7972 project, the activated sign pair shown in Figures 25 and 26 were chosen for the Motorist Warning System Test. The FHWA/Biotechnology project report indicated that among the sets of sign types and combinations tested that this particular pair of activated signs produced generally greater speed reductions than other combinations. As can be seen from Figure 25, the static, constantly displayed "Ice on Bridge" message conjunctive with the "When Flashing" panel infers the existence of ice when the two alternating amber flashers are activated. The potential liability problems associated with faulty operation of this sign are clearly evident. The advance warning sign shown in Figure 26 statically displays a "Bridge Ahead" message. The activated word "Icy" is only visible to the passing motorist when lit.

The four motorist warning signs were located as shown in Figure 27. Exact location of the signs was based upon:

- Review of the manual on Uniform Traffic Control Devices (Ref. 2).
- The California Planning Manual (Ref. 3)
- Discussions with Mr. H. Trosine, California Department of Transportation, District 3, and Mr. F. Hanscom, Biotechnology, Inc.

FIGURE 25
BRIDGE WARNING SIGN

FIGURE 26
ADVANCE WARNING SIGN

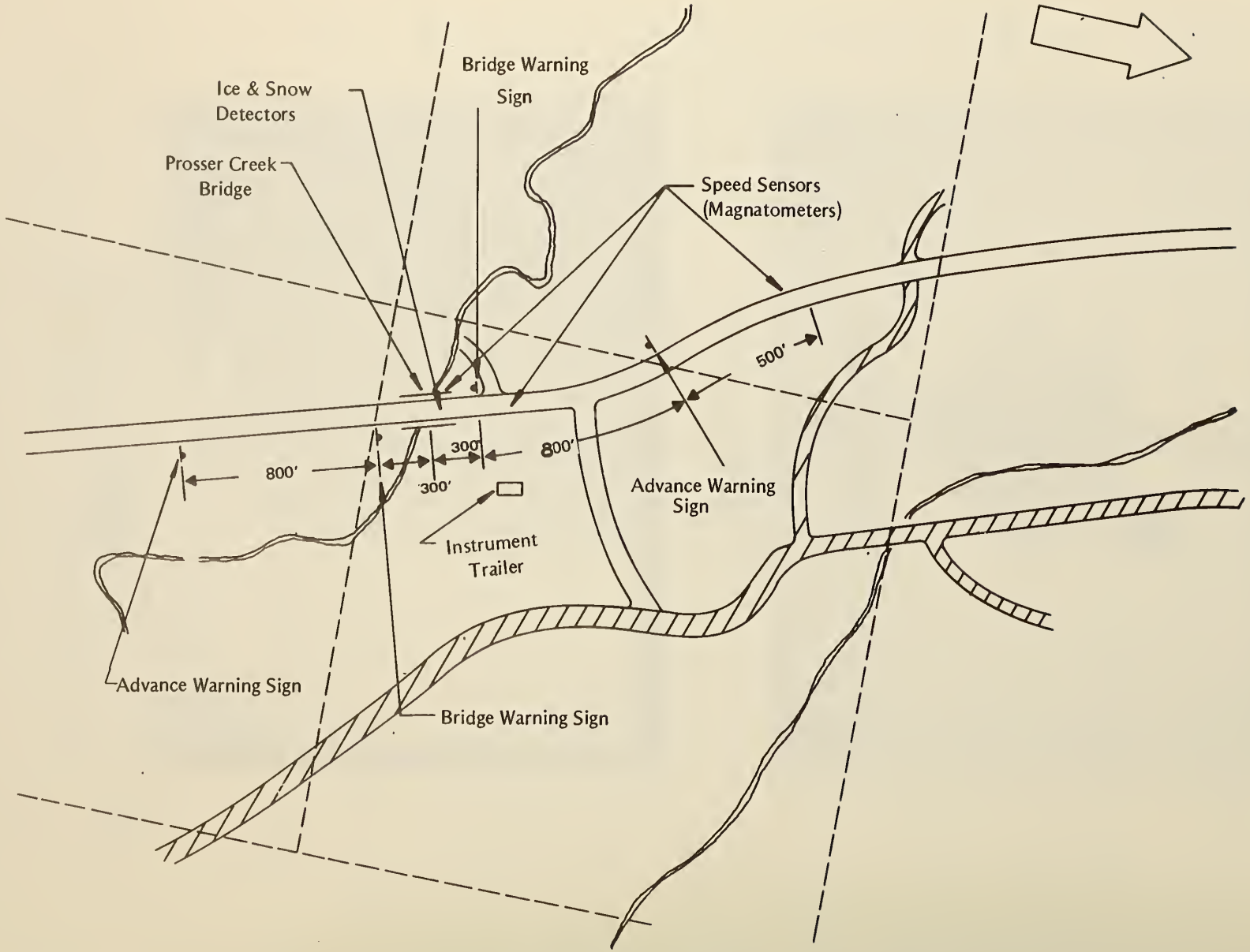


FIGURE 27
MOTORIST WARNING SIGN LOCATION

The bridge located signs were emplaced 225 feet in advance of the bridge structure in each direction. The desirable location of 150 feet in advance of either end of the bridge would have conflicted with an existing "State Route 89N" route marking sign. The advance warning signs were emplaced 800 feet in advance of the bridge signs, or roughly 1025 feet from either end of the bridge structure. California policy would have been to locate this sign a minimal distance of 1200 feet in advance of the bridge structure. Due to the permanent location of speed trap #1, emplacement of the advance warning signs at 1200 feet from either end of the bridge structure might have possibly influenced southbound vehicle speeds as measured by the first speed trap. Analysis plans for the motorist warning experiment made it desirable to have speed trap #1 speeds uninfluenced by the advance warning sign. Roadway geometry and the existence of a large "Hobart Mills" directional sign between speed trap #1 and the advance warning sign made the selected emplacement location the most judicious.

The advance warning sign was emplaced 14 feet from the edge of the roadway according to California policy. Because the bridge approach roadway was located atop a fill area, the signs near the bridge were mounted 6 feet from the edge of the pavement. Sign posts were 4" x 6" as specified by breakaway safety standards.

Although the major portion of the roadway instrumentation was located in the southbound lane, a potential or actual skidding hazard on the bridge would be applicable to both directions of flow. This situation is shown in Figures 28 and 29, which are the southbound and northbound views approaching the Prosser Creek Bridge respectively. The circled portion of each picture reveals an actual heavier concentration of snow covered slush on the east side of the bridge. This situation presents a potential skidding hazard to traffic in either direction. These pictures also reveal that the problem of determining the initiation and termination of an actual skidding hazard may be a difficult decision.

FIGURE 28
POTENTIAL SKIDDING HAZARD – SOUTHBOUND VIEW

FIGURE 29
POTENTIAL SKIDDING HAZARD – NORTHBOUND VIEW

Location of the bridge warning sign relative to speed trap locations are illustrated by a sequence of photographs. Figure 30 shows the driver's view as he passes over the first speed trap. Within view is the first of two Hobart Mills turn-off signs. Approximately 200 feet farther south, Figure 31 shows a portion of the first Hobart Mills sign as well as the advance bridge warning sign which is visible at this point, although it is not clear in the photograph. The roadway view of the driver as he passes alongside the advance warning sign is shown in Figure 32. The second Hobart Mills turn-off sign is in view in Figure 32. Figure 33 presents the driver's view at a point roughly equidistant between the advance bridge warning sign and the second Hobart Mills sign. It is at this point the driver may be first alerted by the alternating flashers of the bridge warning sign. The view alongside the second Hobart Mills sign is seen in Figure 34. At this point the driver is getting his first long range view of the bridge and both lights of the bridge warning sign are in view. Approximately 300 feet farther south, the vehicle passes over speed trap #2, Figure 35. The bridge and long hill south of the bridge are in full view. Location of the bridge warning sign relative to this view is shown in Figure 36 where the State Route 89 marker appears in both Figures 35 and 36. The driver's view at crossing the center of the bridge and speed trap #3 is shown in Figure 37.

5.3.2 Motorist Warning System Control

Due to the temporary nature of the installation of the Motorist Warning Signs, a DC powered system was selected for conduct of the sign test. The two Bridge Warning Signs required 12 volts to drive the incandescent bulbs of the alternating flashers. The Advance Warning Signs were illuminated by two 12-volt fluorescent tubes. The modular box containing the fluorescent bulbs and the message ICY was designed to fit directly behind a cut-out center portion in the Bridge Ahead Warning Sign. Initial plans were to flash the word ICY in the

FIGURE 30
ROADWAY VIEW – SPEED TRAP NO. 1

FIGURE 31
ROADWAY VIEW – ADVANCE WARNING SIGN

FIGURE 32
ROADWAY VIEW – 1000 FEET NORTH OF BRIDGE

FIGURE 33
ROADWAY VIEW – 800 FEET NORTH OF BRIDGE

FIGURE 34
600 FEET NORTH OF BRIDGE

FIGURE 35
DRIVER VIEW AT SPEED TRAP NO. 2

FIGURE 36
BRIDGE WARNING SIGN

FIGURE 37
DRIVER VIEW – CENTER OF BRIDGE

Advance sign however, the 12-volt fluorescent light source precluded this type of display. A permanent installation using standard 110 AC power and incandescent lighting would allow for this more desirable method of transmitting the ICY message.

The actual control of the sign system was selectable from a three position key operated switch in the instrumentation trailer. Two positions were manual on/off positions while the third position was automatic. The automatic position transferred on/off control to a selected sensor output. Due to reasons appearing in Section 5.4.2, this automatic mode was never selected during the sign test.

5.4 Motorist Warning System Test

The motorist warning system test was conducted in the period from March 11, 1975 to April 7, 1975. This period of twenty-eight days was characterized by fourteen separate Hazardous Bridge Events ranging in duration from one hour and twenty-nine minutes to forty-six hours and fifty-seven minutes. As a result of the sensor testing reported earlier and liability aspects of a non-activated system under hazardous bridge conditions, the manual control of the system of four activated signs was selected. The fourteen separate hazardous bridge events resulted from pre-test established criteria for sign activation.

5.4.1 Criteria for Manual Motorist Warning Sign Operation

There are six general surface conditions of concern. They are: Dry, Wet, Slushy, Snow, Ice and Frost. Considering these surface conditions independently for both the approach roadway and the bridge regardless of likelihood of occurrence it is clear that the motorist warning signs should be ON if the bridge surface condition were slushy, snowy, icy or frosty, independent of the road surface condition. On the other hand if the bridge and road were some combination of dry and/or wet the signs should be clearly OFF. This therefore leaves a 4 x 2 matrix in the original 6 x 6 matrix where decisions relative to whether the sign is on or off must be made. The motorist warning sign opera-

tion matrix is shown in Table 6. As can be seen from Table 6, there are eight bridge surface/roadway surface combination states of which four are possible states and four are not likely states. The decision was made not to operate the signs in any of these states since it would be inconsistent with the message carried by the motorist warning signs. It was further felt that only the frost covered roadway and dry bridge condition would actually occur and if it did, it would also occur on one or both ends of the bridge structure.

The well defined bridge and roadway conditions listed in Table 6 normally relate little about the initiation or termination of a hazardous bridge condition. To the conditions previously discussed a primary "sign on" definition was added: If any portion of the bridge over which a wheel or wheels of a northbound or southbound vehicle may realistically travel, contains snow, ice slush or frost, the warning signs will be on. It was reasoned that under the foregoing definition there was realistically at least an increased skidding hazard, as opposed to the totally or partially wet or dry bridge, when some traveled portion contained snow, ice, frost or slush.

In terms of the eight not likely or possible states in Table 6, none occurred during the sign test. However, all hazardous bridge events started and terminated with only portions of the bridge considered as hazardous. Of the fourteen hazardous bridge events, three events involved only portions of the bridge surface being covered with snow or frost during the event.

5.4.2 Hazardous Bridge Events

Based on the previously discussed criteria for motorist warning sign actuation, there were fourteen separate hazardous bridge events occurring during the twenty-eight day motorist warning sign test period. These events, time of occurrence, and resulting bridge surface conditions are listed in Table 7. As was previously stated, there were three events, numbers 1, 4 and 14, where the hazardous bridge surface condition was limited only to a portion of the vehicle travel area of the

ROAD SURFACE CONDITION \ BRIDGE SURFACE CONDITION	DRY	WET	SLUSHY	SNOW	ICE	FROST
DRY & WET	SIGNS OFF		SIGNS ON			
SLUSHY	NL*	NL*				
SNOW	NL*	P**				
ICE	NL*	P**				
FROST	P**	P**				

NL*: Not likely condition

P**: Possible condition

TABLE 6
MOTORIST WARNING SIGN OPERATION MATRIX

TABLE 7

HAZARDOUS BRIDGE EVENTS

MOTORIST WARNING SYSTEM TEST*

SIGN ACTIVATION EVENTS	ON		OFF		DURATION OF EVENT HOURS:MINUTES	BRIDGE SURFACE CONDITION DURING EVENT	SURFACE CONDITION INITIATED BY
	TIME	DATE	TIME	DATE			
1	0719	3/13/75	0840	3/13/75	1:21	SNOW	SNOWFALL
2	1813	3/13/75	1027	3/14/75	16:14	SNOW, ICE, SLUSH	SNOWFALL
3	2138	3/15/75	1204	3/16/75	14:26	SNOW, ICE, SLUSH	SNOWFALL
4	0420	3/20/75	0856	3/20/75	4:36	FROST	DECK TEMPERATURE BELOW DEW POINT
5	1318	3/21/75	1215	3/23/75	46:57	SLUSH, SNOW, ICE	SNOWFALL
6	0000	3/24/75	0923	3/24/75	9:23	SNOW, SLUSH	SNOWFALL
7	0235	3/25/75	0935	3/25/75	7:00	SNOW, SLUSH	SNOWFALL
8	1102	3/25/75	1255	3/25/75	1:53	SNOW	SNOWFALL
9	0248	3/27/75	0700	3/27/75	4:12	SNOW**	SNOWFALL
10	0604	3/31/75	0845	3/31/75	2:41	BLACK ICE	WET PAVEMENT/COLD TEMPERATURE
11	1927	4/3/75	1241	4/4/75	17:14	SNOW, SLUSH, ICE	SNOWFALL
12	1551	4/4/75	1141	4/5/75	19:50	SNOW, SLUSH, ICE	SNOWFALL
13	2001	4/5/75	0936	4/6/75	13:35	SNOW, SLUSH, ICE	SNOWFALL
14	0519	4/7/75	0648	4/7/75	1:29	SNOW	BLOWING SNOW

* TEST PERIOD: 1700 HOURS 3/11/75 THROUGH 0945 HOURS 4/7/75

**COLLECTED ON BRIDGE DECK LIKE FROST

bridge surface. The frost event on March 20, 1975 was a low accumulation of bridge surface frost confined primarily to the west side of the bridge, i.e., the southbound traffic lane. Figures 38 and 39 depict two typical hazardous bridge conditions where snow cover was the principal reason for the hazard condition. A very marginal hazard condition is shown in Figure 40 where the bridge cover was a very thin layer of snow.

An event of particular interest was the "Black Ice" condition in the morning hours of March 31, 1975. The black ice condition is one where the view of the road, particularly during darkness, appears nearly identical to a wet surface on black asphalt paving. This particular event resulted from a light snowfall occurring on a cooling, but above freezing, road and bridge. The snow melted immediately but due to low temperatures and a lack of traffic neither the road or bridge dried following cessation of the snow. As both the bridge and road surface continued to cool the wet pavement froze, creating the black ice condition on both the bridge and roadway. It should be noted that the coldest roadway and bridge surface conditions normally occurred between 0500 - 0800 hours dependent on the time of year. Figures 41 and 42 depict a close-up view of the road surface under car headlight illumination and a view of the northside bridge sign during darkness. Figure 44 shows south approach to the bridge under increased light conditions.

5.4.3 Snow and Ice Sensor Performance

In spite of the nearly nine months operational time of the Prosser Creek site it was impossible to exactly quantify either the false alarm rate (frequency) or the likelihood of detection of an icy bridge event. Such quantification would require visual verification of the bridge surface conditions at onset and termination of hazardous or icy bridge surface conditions. The data acquisition system was designed around a Nova 1210 Processor and only daily observer monitoring (between 0400 - 0800) was conducted. These early

FIGURE 38
HAZARDOUS BRIDGE CONDITION

FIGURE 39
HAZARDOUS BRIDGE CONDITION

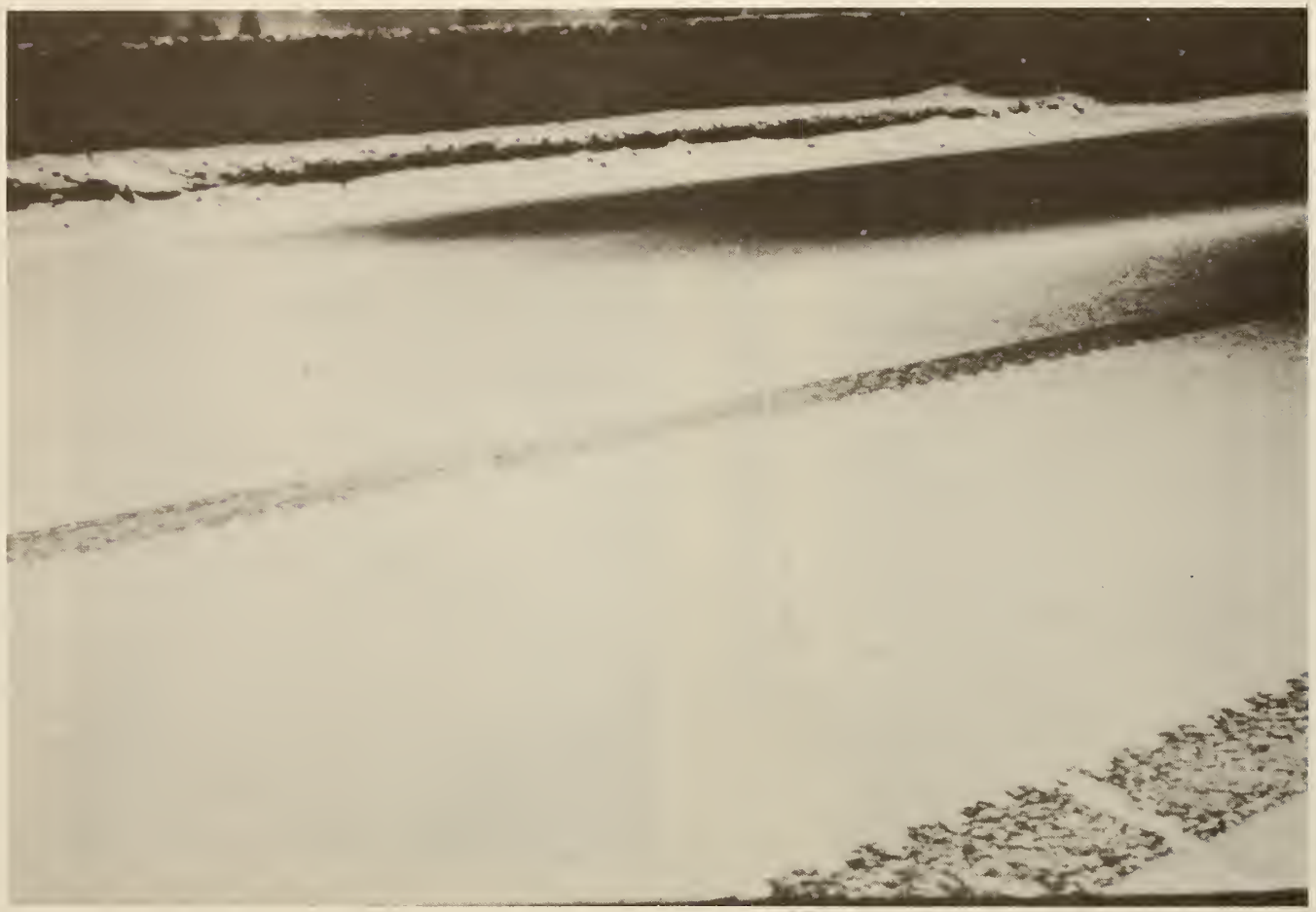


FIGURE 40
MARGINAL BRIDGE HAZARD CONDITION

FIGURE 41
ROADWAY UNDER HEADLIGHT ILLUMINATION – BLACK ICE CONDITION

FIGURE 42
BRIDGE WARNING SIGN – BLACK ICE CONDITION

FIGURE 43
BRIDGE SURFACE VIEW – BLACK ICE CONDITION

FIGURE 44
BRIDGE AND SOUTH APPROACH – BLACK ICE CONDITION

morning hours were excellent times to pick up hazardous conditions, however these hours rarely overlapped both the onset and termination of events.

A major by-product of the Motorist Warning System Test was that the twenty-four hour surveillance necessary to manually operate the four activated signs would form the actual bridge surface condition data base against which individual sensor system output conditions could be measured. It would therefore be possible to quantify the performance of the sensor systems over a reasonable sample of events. The fourteen events described in Table 7 is considered a good sample of events.

The performance of each sensor system is documented in subsequent sections.

5.4.3.1 Holley System Performance

The results of summer 1974 testing of the Holley system is reported in Section 5.1. The performance during the second year of the two Holley systems was extremely disappointing. What is referred to as Holley #1 system failed following final calibration and prior to the start of the sign test. This failure was the typical Holley failure experienced throughout the project, i.e., a failed heater and thermistor in the heated head. This thermistor failure precluded the switching of the two Holley heads. This problem on Holley #1 system was followed by a similar failure on Holley #2 system on March 15th. During the initial four days of the motorist warning test the Holley #2 system had produced no icy or alert conditions. It was due to this lack of activity that an attempt to re-calibrate the system was made and the system failure discovered.

A final attempt to create a working Holley system was then made by using one good head from the Holley #1 system and another good head from the Holley #2 system. These two heads were connected to the Holley #1 controller. This hybrid Holley system also failed to produce any output activity in spite of the occurrence of icy bridge

events. A checkout of the system on March 29th, following ten days of inactivity revealed that the heated head had now lost its conductivity probe. This final failure meant that three of the four Holley heads were useless. Any attempt to restore the Holley systems would mean conducting road work during the sign test and in severe weather conditions, i.e., replacing the failed bridge deck embedded sensor heads. Therefore the final Holley system was shut down on 29 March with no activity being recorded for the entire test period.

5.4.3.2 Cytronics System Performance

Based upon the accumulated testing of the Cytronics system it is recognized by its manufacturer and MBAssociates that the heater power applied to the three heads in successive 30 minute time intervals is insufficient to melt any appreciable level of ice or snow accumulation on the sensor head. Therefore its logic of detection based upon latent heat of fusion will generally not function to output the desired alarm or icy condition.

Over the sign test period the Cytronics #2 system was nearly inactive, producing only two icy conditions. The first of these was a 28-minute false alarm occurring between icy bridge events #3 and #4. The second alarm occurred two minutes prior to sign deactivation on the final hazardous bridge event, #14. Regarding the frost event, #4 and the Black Ice event #10, neither of the Cytronics systems, #1 or #2, produced alarms during these events. Both frost and the thin layer of Black Ice were visually observed on the Cytronics heads during these two events.

Cytronics #1 system was somewhat more active. This system produced five (5) one minute false alarms and 17 false alarms ranging in duration from 24 - 27 minutes each. Nine other Cytronics #1 alarms either overlapped or were contained within the events. Overlapped hazardous bridge events were numbers 1,. 6, 7, 11, 13 and 14, all other events were completely missed.

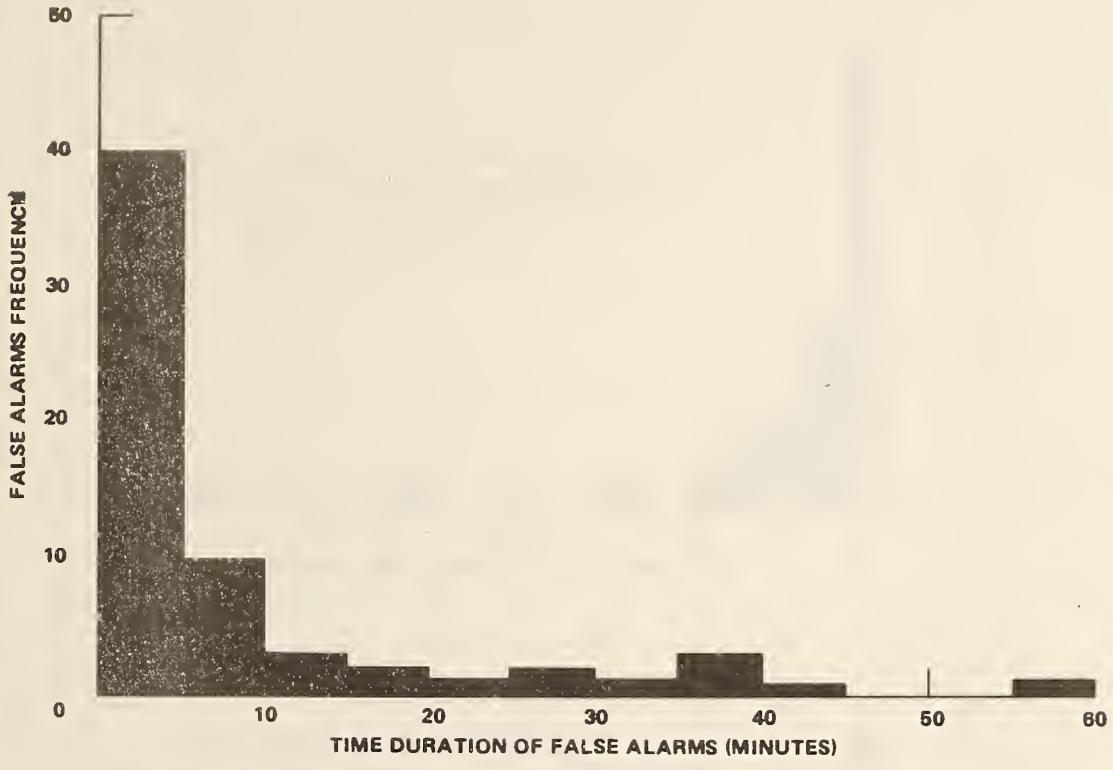
The performance of Cytronics #1 system can be analyzed by supposing that the motorist warning system was activated by an icy output of the sensor. Deactivation would occur when the controller output changed from the icy output condition. Under the foregoing assumptions and, excluding the total false alarm on times, the motorist warning system would have been on too early or off too late for a total time of one hour and 52 minutes, over nine alarms and six distinct events. In terms of Cytronics #1 controlled motorist warning system on time considered valid, this totalled two hours and 10 minutes out of 172 hours and 36 minutes of actual sign operation over 14 hazardous bridge events. This corresponds to correct operation of 1.3 percent of the time.

5.4.3.3 SSI System Performance

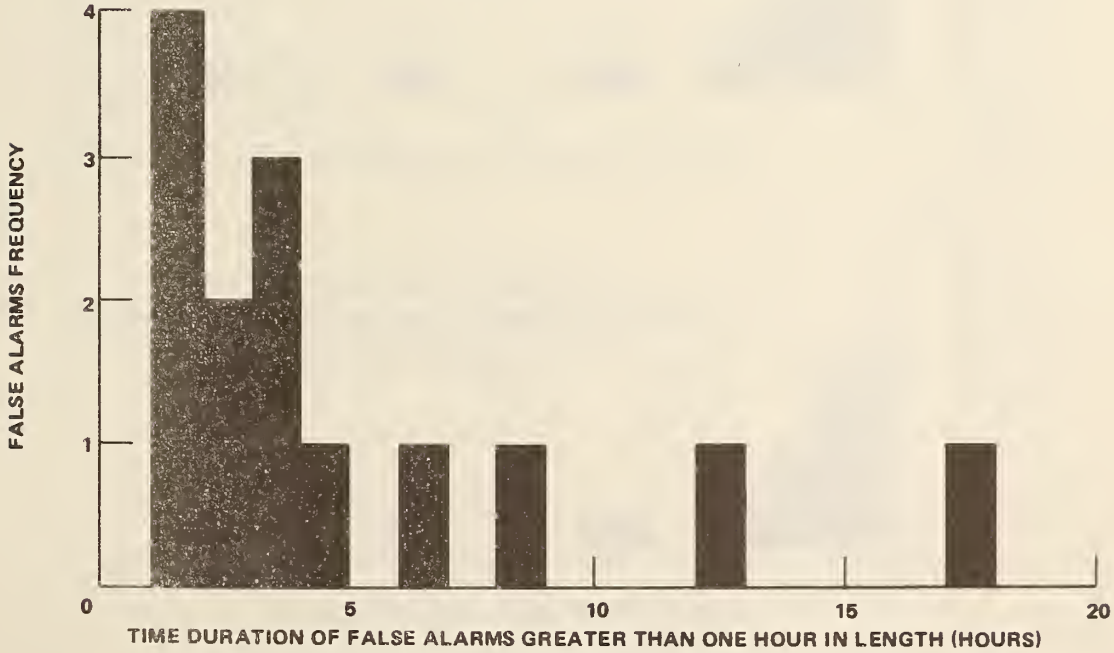
Of the three sensor systems tested, the SSI Systems #1 and #2 provided the most activity. SSI unit #2 unfortunately failed three days into the test. This is attributed to some rather harsh treatment given to the epoxy head that is buried in the bridge deck. This treatment was apparently inflicted by tire chains which caused a considerable amount of chips and cracks in the head. This damage may have resulted in the unit failure. This difficulty can be expected with the epoxy head in a harsh roadway environment. Decreased head surface area, flush with the road surface, may decrease the problem but may not solve it where vehicle chains are used. The secondary problem with the SSI epoxy head is that the head itself is likely cooler or warmer than the deck surface. On numerous occasions early morning visual checks of the sensor heads revealed thin frost layers on the SSI witness plate while the bridge deck surface was frost-free. This "colder than deck" hypothesis is reinforced by continued observation of the collection of snow or slush on saw cuts in the bridge deck which were also epoxy filled. These epoxy filled cuts were first to collect snowfall and last to give up slush concentrations when the bridgedeck slush accumulation was melting.

The performance of SSI unit #2 is not reported during the sign test since its duration was short. On the other hand SSI unit #1, although also suffering some witness plate damage, survived the entire test period. The performance of this unit is examined in detail relative to the 14 hazardous bridge events.

The false alarm statistics of SSI #1 system were based on an assumption that only the icy output of the sensor system would actuate a motorist warning system. All icy sensor system outputs and their time duration which did not overlap the 14 icy bridge events were strictly classified as false alarms. A frequency plot of these alarms and their duration is shown in Figure 45. Figure 45 was broken into two diagrams, one for those alarms of 60 minutes duration or less and the second or lower diagram depicting alarm frequencies of one hour or greater in time duration. There appeared to be a number of short time period alarms which occurred concurrently with passage of a southbound vehicle over the bridge. These short term alarms did not always occur but the reason or cause for interaction of the sensor with vehicles was never explained. Based upon this unexplained interaction the false alarm rate was re-analyzed. Since it would be a minor problem to design a fixed time interval alarm delay logic, a SSI driven motorist warning system with fixed time interval delay, upon sign activation and deactivation, would eliminate some short time interval responses. A fixed five minute delay would activate the sign system when the SSI sensor output constantly held the icy condition for five minutes. Once the sign system was on it would also take five continuous minutes in a non-icy sensor status to turn the motorist warning system off. The false alarm data of Figure 45 was analyzed based on a delay logic of 5, 10, and 15 minute delay constants. The frequency diagrams of false alarm duration corresponding to each delay constant are shown in Figure 46. Table 8 depicts the false alarm statistics for four different SSI #1 driven warning sign systems. The variance to mean ratio depicted in Table 8 is one measure of predictability or distributional spread. These numbers are extremely high as evidenced by the frequency diagrams in Figures 45 and 46.

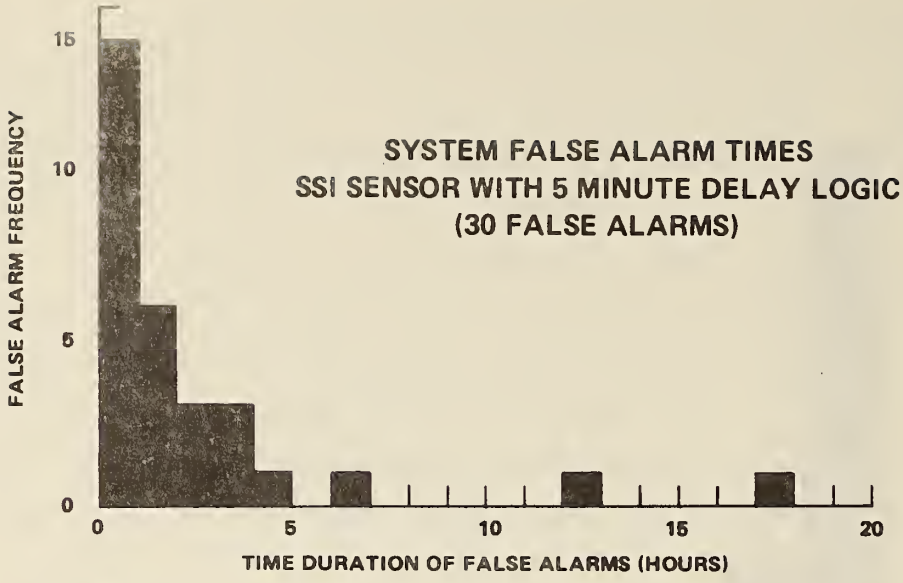


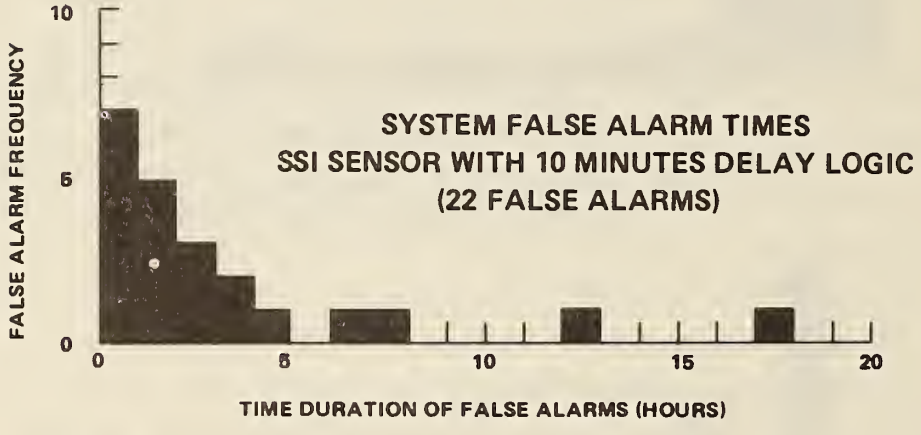
SYSTEM FALSE ALARM TIMES LESS THAN ONE HOUR IN LENGTH
SSI SENSOR (68 ALARMS) FALSE



SYSTEM ALARM TIMES GREATER THAN ONE HOUR IN LENGTH
SSI SENSOR (14 ALARMS) FALSE

FIGURE 45
SSI NO.1 FALSE ALARM DATA





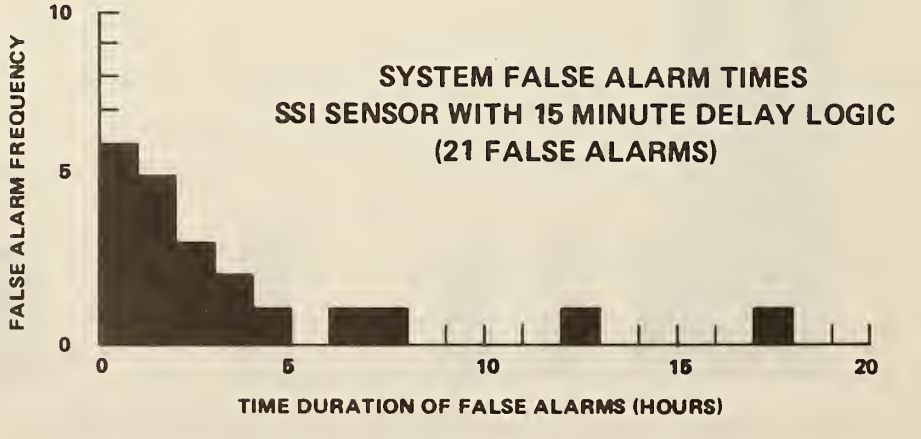


FIGURE 46
SSI FALSE ALARM DATA

TABLE 8
FALSE ALARM ANALYSES BASED ON ALTERNATIVE SSI NO. 1
DRIVEN MOTORIST WARNING SYSTEMS

SYSTEM TYPE	NUMBER OF FALSE ALARMS	FALSE ALARM DURATION		
		SAMPLE MEAN ($\bar{X}$)	SAMPLE STANDARD DEVIATION (S_x)	VARIANCE TO MEAN RATIO ($S_x^2/\bar{X}$)
ALARM BASED UPON "ICY" OUTPUT OF SSI SENSOR	82	59 MINUTES	2 HRS 39 MIN	428
ALARM BASED UPON "ICY" OUTPUT OF SSI SENSOR COUPLED TO A 5 MINUTE DELAY LOGIC**	30	2 HRS 26 MIN	3 HRS 45 MIN	347
ALARM BASED UPON "ICY" OUTPUT OF SSI SENSOR COUPLED TO A 10 MINUTE DELAY LOGIC	22	3 HRS 19 MIN	4 HRS 15 MIN	327
ALARM BASED UPON "ICY" OUTPUT OF SSI SENSOR COUPLED TO A 15 MINUTE DELAY LOGIC	21	3 HRS 27 MIN	4 HRS 18 MIN	320

* DATA BASED UPON SSI# 1 SENSOR PERFORMANCE FROM 11 MARCH TO 7 APRIL 1975

** SYSTEMS DELAY LOGIC WOULD TRIGGER AN ALARM BASED UPON THE SSI SENSOR HOLDING AN "ICY" CONDITION FOR A FIXED TIME INTERVAL. THE END OF THE ALARM WOULD OCCUR WHEN THE SSI SENSOR OUTPUT CHANGED FROM "ICY" CONDITION FOR THE SAME FIXED TIME INTERVAL.

Performance of the SSI #1 sensor relative to its reliability in triggering a motorist warning system is depicted in Table 9. This analysis is based upon the sign system being tied directly to the icy status of the SSI #1 sensor system. The 5, 10 and 15 minute delay logic systems would produce little change in the detectability portion of the analysis. Although highly superior to the type of performance of the other sensor systems, it should be noted that only three events were covered more than 90% of the total event time and one of these produced a six hour and thirteen minute event out of an actual one hour and twenty-nine minute event. Five of the fourteen actual events were never seen by the sensor.

5.4.4 Motorist Warning System Evaluation

The amount of snow or slush accumulation on the roadway is the major variable influencing traffic speed in the Prosser Creek area. Due to the black road policy of the California Department of Transportation in this region, a snow-covered major highway interconnecting I-80 in the Sierra Nevada is a rare event of short duration. Under conditions of very heavy snowfall, the primary commitment of snow removal equipment is to I-80. It is only under these extreme conditions that there is appreciable snow accumulation on the secondary state highways in the Truckee area.

Such conditions are reflected by speed data shown in Figure 47. This five-day period, 27 February 1974 through 3 March 1974, depicts average traffic speed over the Prosser Creek Bridge. As can be seen from this figure, snow accumulation on State Route 89N is the major variable controlling traffic speeds. There were two periods in the five-day period of appreciable amounts of snow accumulation on State Route 89N in the Prosser Creek area. Thirty to forty mph speeds occurred in the evening of 28 February 1974 and during the morning hours of 1 March 1974. A similar period of low traffic speeds occurred

ICY BRIDGE CONDITIONS EVENT**	TOTAL EVENT TIME	NUMBER OF SENSOR ALARMS OVERLAPPING THE ICY BRIDGE CONDITIONS EVENT	PERCENT OF EVENT TIME COVERED BY SENSOR ALARMS	AMOUNT OF SENSOR ALARM TIME NOT OVERLAPPING THE EVENT	COMMENTS
2	16 HRS 14 MIN	1	94	---	ON 24 MINUTES LATE OFF 37 MINUTES EARLY
3	14 HRS 26 MIN	1	95	1 HR 21 MIN	ON 1 HR 24 MIN EARLY OFF 41 MINUTES EARLY
5	46 HRS 57 MIN	10	84	1 HR 13 MIN	ON 1 HR 13 MIN EARLY OFF 2 HRS 5 MIN EARLY OFF 9 TIMES DURING EVENT
7	7 HOURS	2	65	---	ON 5 MINUTES LATE OFF 2 HRS 18 MIN EARLY OFF ONCE DURING EVENT
10	2 HRS 41 MIN	1	93	2 HRS 29 MIN	ON 2 HRS 30 MIN EARLY OFF 12 MINUTES LATE
11	17 HRS 14 MIN	4	61	34 MINUTES	ON 34 MINUTES EARLY OFF 1 HR 53 MIN EARLY OFF 3 TIMES DURING EVENT
12	19 HRS 50 MIN	12	29	---	ON 3 MINUTES LATE OFF 2 HRS 2 MIN EARLY OFF 11 TIMES DURING EVENT
13	13 HRS 35 MIN	2	14	3 MINUTES	ON 3 MINUTES EARLY OFF 11 HRS 3 MIN EARLY
14	1 HR 29 MIN	1	100	4 HRS 44 MIN	ON 4 HRS 22 MIN EARLY OFF 22 MINUTES LATE

* EVENT DESCRIBED IN TABLE.
** EVENTS 1, 4, 6, 8, AND 9 WERE MISSED BY THE SSI# 1 SENSOR.

TABLE 9
SSI#1 ALARMS OVERLAPPING ICY BRIDGE CONDITION EVENTS *

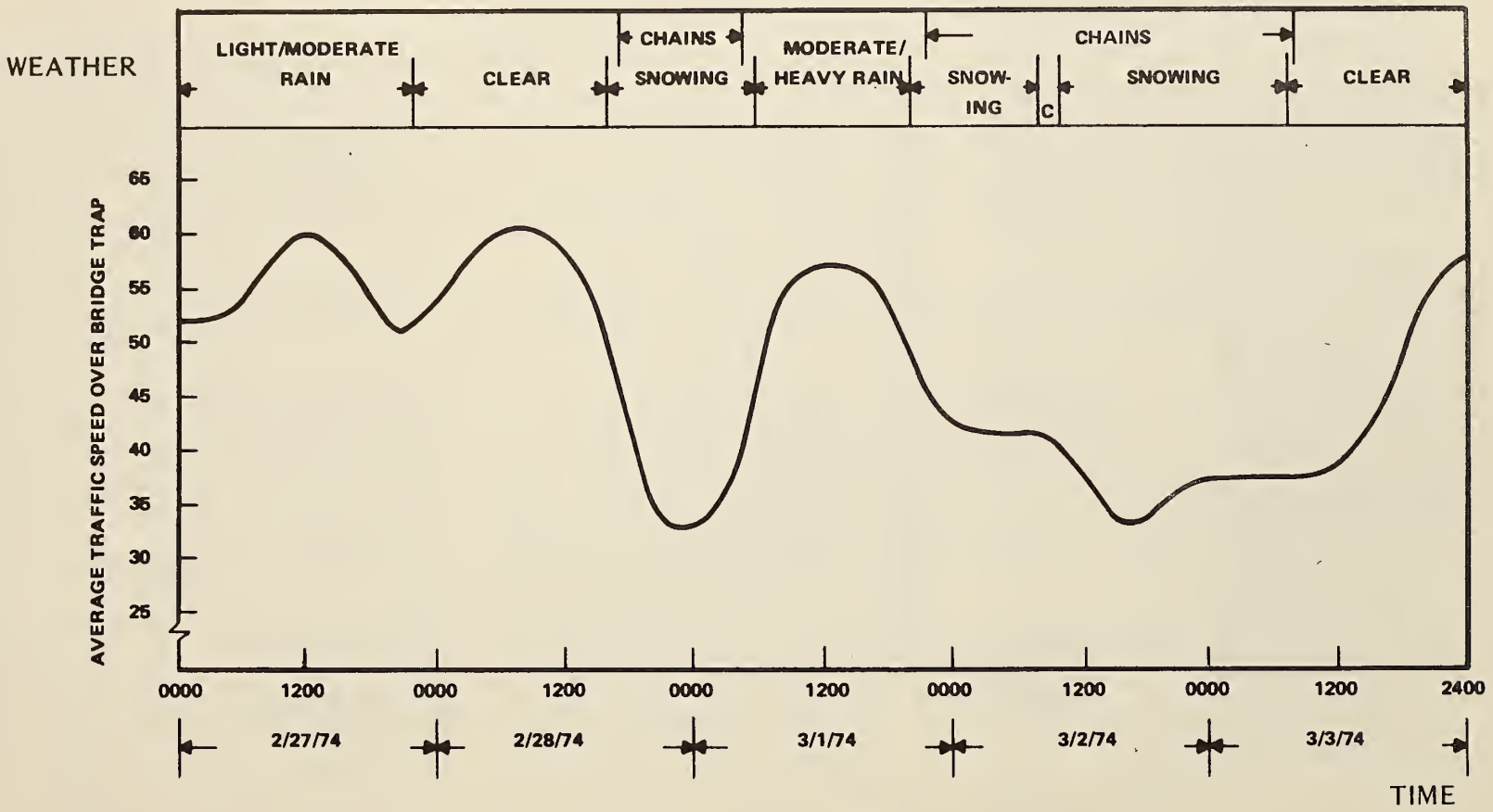


FIGURE 47
PROSSER CREEK BRIDGE TRAFFIC SPEED

on the night of 1 March 1974 and continued through the following day as well as midday of 3 March 1974. The information displayed in Figure 47 is typical and along with similar data collected during the two winters of testing demonstrates that spot speed analysis for evaluation of a motorist warning system could be greatly influenced by differing road conditions during the two comparison periods.

The overall sample vehicle driver population in this area is actually a combination of two relatively distinct subgroups. The first of these are the local drivers. These indigenous drivers are familiar with the area and generally drive vehicles equipped for winter driving. Many locals operate four-wheel drive vehicles equipped with snow tires. The second population is the visitor or transient whose family auto or other vehicle has only tire chains available to adapt to the continuum of conditions. Therefore, under adverse conditions one is likely to observe the two different populations driving two distinct speeds. This condition is true in spite of the 25-mph maximum speed imposed during chain control conditions. The proportion of each population which makes up each daily sample of roadway traffic is dependent upon the day of the week, time of the year, and the local weather conditions.

5.4.4.1 Prosser Creek Traffic

A program was written to tabulate and analyze traffic speeds recorded at Prosser Creek. The analysis included a breakdown by cars and trucks subcategorized by daylight and dark driving conditions. A third stratification is three non-overlapping environmental conditions:

1) Chain controls in effect
2) Snowing and no chain controls in effect
3) Clear--all conditions not covered by (1) and (2)

This program performed daily tabulations as well as monthly and total period tabulations. A tabulation of this data from 31 December 1973 through April 1974 provides some interesting results. The data set starting date of 31 December 1973 was chosen to encompass the beginning of a snow storm. The monthly data summaries are presented in Appendix C, which includes a detailed discussion of the vehicle speed data. Table 10 displays a composite summary of the data for the 1974 test period. The sample mean, standard deviation, and sample size is denoted by MEAN, SD and N respectively.

Only speeds between 10 mph and 85 mph were analyzed. Vehicles triggering Speed Trap 1 within 9 seconds of the preceding vehicle were eliminated from analysis as being in a possible car following mode. In addition, some speed trap output readings were assessed as erroneous and these vehicles were tabulated but not analyzed. The total sample size of such non-analyzed vehicles are also shown in the table. All speeds are those recorded at Speed Trap 1.

Average speeds across environmental conditions and time of day show little other than speeds are slightly slower at night than daytime and maximum speed differentials occur as the road conditions go from clear to snow to chain conditions. It is interesting to note from Table 10 that the overall average truck speeds are greater than car speeds for all categories except daylight snow conditions without chain controls. Another interesting result is that only three of the twelve categorizations show mean speeds less than the 55-mph speed limit imposed on 1 January 1974. The only category possibly possessing 85th precentile speeds less than the 55-mph limit is the night category with chain controls. This category represents approximately 165 vehicles out of a total sample of 16,900 vehicles over this four-month time interval. Under ideal or clear weather traffic conditions, a standard deviation of approximately 10% of the mean traffic

TABLE 10

Summary Speed Data
(I2-31-73 - 4/40-74)

		CAR				TRUCK			
		Chains	Snow	Clear		Chains	Snow	Clear	
DAY	Mean	56.8	60.0	60.6		55.4	60.3	61.8	
	S.D	10.2	9.0	8.5		11.8	9.5	3.1	
	N	493	452	6740		170	274	3967	
NIGHT	Mean	46.1	54.2	56.8		46.8	57.3	60.6	
	S.D.	11.3	9.4	9.1		13.0	10.6	9.3	
	N	129	106	1485	All Conditions	48	32	800	All Conditions
TOTAL DAY AND NIGHT	Mean	54.6	58.8	60.3	59.3	53.5	60.0	61.6	61.2
	S.D.	11.3	9.4	8.7	9.0	12.5	9.7	4.7	5.9
	N	622	558	8225	9405	218	306	4767	5291

Miscellaneous Data

Speed Gaps Less Than Nine - 1771
Invalid Speed Values - 139
Speeds Greater Than 85 - 169
Speeds Less Than 10 - 158

speed is expected. In fact, the standard deviations exceeded the sample mean by more than 10 percent under both chain control conditions and snowing conditions. Even the larger sample "total profile" has a standard deviation between 25 and 30 percent of the sample mean speed.

This large deviation is explained by the previously mentioned difference in driver populations as well as varying snow depth under the condition of chain controls.

5.4.4.2 Motorist Warning Experiment

Based on the foregoing discussion and cursory analysis of the traffic behavior through the sequence of the three speed traps at the Prosser Creek Bridge, it was decided that a special type of analysis was needed to evaluate the speed effects of the warning sign experiment. In an effort to overcome the variational effects of the two different underlying driver populations and the gross variation in environmental conditions, it was decided to classify the impact of these variations by use of an initial speed classification based upon each vehicle's speed at the initial speed trap. This speed is the entrance speed onto the test roadway section. Thus, the vehicle's speed at Traps 2 and 3 relative to its initial speed was analyzed to determine the differential in speed caused by the presence of the motorist warning system. The typical outliers expected in such an analysis are:

1) The individual whose Trap 1 speed is excessively low for some reason, other than roadway condition, which subsequently disappears yielding Trap 2 and 3 speeds not due to the hazard warning system, and

2) The individual whose Trap 1 speed is nominal for his type and roadway condition but whose Trap 2 and/or Trap 3 speed is affected by an extraneous event other than roadway conditions or the warning system.

The fundamental assumption of the analysis is that the driver type and environmental conditions combine to produce an initial speed category observation at Trap 1. The behavior at Traps 2 and 3 is assumed to be related to the initial speed and roadway geometry, and warning signs if they exist. It is further assumed that the initial speed is a psuedo measure of driver population and that basic adjustments to overall road surface conditions have already been made. Since the signs impact the vehicle driver inside the first trap, pre- and post-sign analyses are thus made by comparing Trap 2 and Trap 3 speeds for each input speed category.

5.4.4.3 Motorist Warning Experiment Results

Appendix C of this report contains a detailed analysis of the data collected during the motorist warning experiment. This section attempts to summarize the findings presented in Appendix C. The data base for the sign test was extracted from those conditions where the signs were activated and SR-89N chain controls were in effect. Of the approximately 350 vehicles observed during "sign on" condition only 104 vehicles satisfied the additional constraints of chain controls in effect, gaps of nine seconds or more and no trap speeds of 5 mph or less. These constraints were applied to eliminate possible biases introduced by exogenous events other than the warning signs themselves.

The first and notable result of the analysis indicated that there was a significant reduction in speeds of both trucks and cars entering the test area between the 1974 and 1975 test data periods. Since these speeds are measured prior to the vehicles encountering the warning signs, it is assumed that this is a result primarily of a more severe average environmental setting in the 1975 test period.

The motorist warning sign test produced some significant increases in deceleration as approach vehicles apparently heeded the pair of warning signs on the north side of the Prosser Creek Bridge. This conclusion can be made in spite of a small data sample. Statistically significant results produced by the sign system are summarized as:

- Increased deceleration of cars in the daytime for entering speeds between 31-60 mph
- Increased deceleration of high speed (61-75 mph) trucks during the day
- Increased deceleration of nighttime cars in the 36-40 mph category.

Although the sample size was insufficient for statistical testing, it is also reasonably clear that:

- 1975 car decelerations in approaching the bridge under the sign experiment were larger than the corresponding 1974 base data vehicles for nearly all speed categories, both day and night
- The truck speed deceleration increases due to the signs were similar to that for cars; however, truck behavior is slightly different than cars in that more trucks decelerated earlier in the presence of the signs although the Trap 2 to Trap 3 deceleration was not significantly different.
- Based upon the data and the observer's comments it is likely that minimal approach speeds to the bridge were lowered by the presence of the sign and the distance from the bridge at which the minimal speed occurred was likely shifted closer to the bridge.

One of the most interesting results of the analysis is that within the 30-75+ mph approach speeds there is almost a universal constant deceleration by vehicle type during daytime where the signs produced an increase in the value of the constant. On the other hand the corresponding nighttime data seems to reveal a slightly increasing deceleration as a function of increased initial speeds.

The most reasonable interpretation of these findings is that the warning signs do have a significant impact on driver behavior. The results agree with basic intuition in that the vehicles with the lower speeds at the point of encounter with the warning system make the smallest adjustments, while the highest speed vehicles make the largest adjustment. Further the adjustment in speed throughout the range is greater at night when visibility is lower, than it is in the daytime. Trucks, which probably have the more experienced drivers tend in the large to make smaller corrections than the cars do.

The presence of the warning signs clearly has a significant effect on driver behavior, causing him to slow sooner and thus providing more flexibility to adjust to the hazard. Further, the average driver crosses the hazard at a slower speed when the signs are in operation. More significantly, however, total population variation in speed appears to be less when the signs are present than when they are not. This result in the data should be viewed with some caution since the signs presented a new experience for drivers in the Prosser Creek area and the fact that this appears to have reduced the population variance may simply imply that drivers responded with similar caution in the face of a strange experience. The time duration required for driver population adaptation to a new experience, such as the sign, is not known. It is believed that the signs were present long enough for indigenous drivers to become accustomed to them, but this premise cannot be tested with the data.

If, in fact, the reduction of population speed variance in the presence of the signs is a real, sustainable result of the signs, the finding is highly significant. Since it is the outlier and not the average driver that has or causes problems in the presence of a hazard, the tendency of the sign influence to pull the distribution of behavior closer to the average should result in safer overall traffic operations.

One other result worthy of further attention is the fact that for approach speeds in excess of 30 mph all vehicles tend to decelerate at a constant rate. A number of inferences may be drawn about this phenomena, one of which is that most drivers have their own sense of "safe" driving speed and each knows or has a sense of what that speed is. The difference between the no-hazard and the eminent hazard speed for each such driver is then a relative constant adjustment. Another possible interpretation is that most drivers share a common sense of what constitutes a reasonable deceleration rate in the face of a possible hazard, independent of their own speed at the time of being warned of the eminent hazard. In any case, this result appears to deserve further consideration in future experiments. For example if a hazard condition occurs of a nature more severe than the population encountering it is accustomed, then a two-stage warning system could possibly bring the faster drivers down to slower speeds in stages. This method is, of course, in use already in a number of states where major throughway reconstruction work is being done.

5.4.4.4 Key Summary Results

Certain salient results of this program deserve highlighting. These are:

- At the present, no known snow, ice and/or frost detection system exists of sufficient sensing capability or reliability for use as an independent, remote warning device.
- Drivers in the large are basically competent and driver behavior is a better and more consistent indicator, at present, of an impending snow/ice hazard than any of the known available detection systems.

- Predictive systems for use in conjunction with signs of the "bridge may be icy" type are within the state-of-the-art. Such systems appear, at present, to be as likely to warn of a dry bridge as possibly icy as they are to warn of an actual icy bridge.
- Drivers respond to a preferential hazard warning system in a positive manner. More significantly, it appears that indigenous drivers respond to such a system within their local environment.
- Drivers tend to respond to a hazard warning system in a consistent manner independent of their behavior prior to encountering the warning.

APPENDIX A

HAZARD WARNING SYSTEM REQUIREMENTS

Based upon MBA's two years of winter testing of snow and ice sensors a number of very pertinent observations can be made which should be of use to highway officials planning a motorist warning system. These are:

- Typical hazardous conditions such as snow, ice, slush, frost or even wet pavement which can produce skid/accident potentials, should not be thought of in a dicotomous sense, i.e., the hazard condition or no hazard condition. Onset and termination of a potential skidding hazard will typically occur non-uniformly over a bridge or roadway section.

- Potential skidding hazards under the right environmental conditions may only occur on sections of a bridge deck. This situation is commonly observed in winter driving where certain sections or portions of the roadway accumulate snow, slush or ice faster than other sections. Dependent upon environmental conditions the warmer sections may not be covered before the ambient temperature rises and the entire road clears again. The reverse condition is often seen in mountainous terrain where it may take a week or more of warm weather for a sheltered section of road to clear, following snow and/or ice accumulation.

- At one time or another each of the sensing systems tested have exhibited the behavior of oscillating between icy and non-icy states. This oscillatory behavior would not be a desirable characteristic of a sensor operated motorist warning system. It is likely that a number of the short duration alarms were instituted by interaction between the sensor heads and the tires of passing vehicles. Such short term behavior can be eliminated from a motorist warning system by delay circuitry.

Based upon the foregoing observations a few planning guidelines are discussed relative to the design of sensor activated motorist warning system.

1.0 GUIDELINES TO SYSTEM DESIGN

Snow, ice and/or frost sensing systems at the present state-of-the-art are not sufficiently reliable to operate a motorist warning system. Even with considerable improvement it is not clear that the intermittent, short term false alarm will be cleared up by future improvements. For the highway department which is planning such systems, a few design planning guidelines are listed below.

1) Consideration should be given to a multiple sensor array for detection of a hazard event since there will likely be non-uniformity of conditions on the bridge surface. Multiple sensors will increase detection likelihood but will also increase the false alarm rate which is presently too high relative to the sensors tested.

2) With any sensor system it would be well to consider use of additional logic circuitry to eliminate short duration alarms. This is in addition to the logic requirements imposed by using multiple sensors.

3) The type of activated or changeable message warning sign should be analyzed. Particular attention should be given to the ramifications of both types of errors: false hazard condition and failure to detect an actual hazard. Particular attention should be paid to the implications of the non-detected hazard and what deactivation of the warning system implies to the passing motorist.

4) A manual bypass of automatic operation is absolutely necessary. The motorist warning system could be designed to communicate a status of inoperability which is basically the reason for the manual bypass of the system.

5) Consideration should be given to other more reliable hazard warning systems whose primary source of hazard information is not the typical snow and ice detector. This is discussed in Section 3.0.

2.0 SYSTEM PERFORMANCE REQUIREMENTS

Based upon experience gained during conduct of this project there appears to be two interrelated probabilistic performance measures which might be used to specify the performance requirements relative to hazard detection. In addition there should be a design constraint relative to the oscillatory behavior of the sensing system, i.e., the system should not oscillate between alarm and no alarm status. The three probabilistic measures of performance are discussed below:

1) Given there is a sensor alarm there should be a requirement which states there is a probability that the alarm is a real hazardous event. This can be construed to relate the relative frequency of true hazard alarms to false or no hazard alarms. Dependent upon the use of the information this percent will have varying values, e.g., motorist warning versus maintenance crew warning systems. If motorists are expected to have confidence in a hazard warning system it should be 90% reliable.

2) There is a performance measure relative to the degree of coverage of a hazard event, i.e., a percent of time the sensor alarm covered the hazard event. It would be desirable if the sensor alarm would cover 100 percent of each hazardous event, alarming just prior to the event and terminating just after the event. On the practical side it would be desirable if at least 95% of the hazardous event was covered by the sensor alarm. In terms of the amount of false alarm time tolerable prior to initiation of a real event, certainly 15 minutes would be tolerable. It should be noted that if the Cytronics system were a perfect sensor, its one-half hour cycle length implies it will be on late and off late relative to the exact hazard interval. The expected lateness is one-half cycle or 15 minutes.

In the case of maintenance crew warning systems the false alarm rate or percent of erroneous hazard warnings could likely be greater than 1 in 10. The second requirement relative to coverage is not of real concern. The more important facet is early detection or prediction.

3.0 ALTERNATIVE SENSOR ACTIVATED WARNING SYSTEMS

Considering the status of existing snow and ice sensing systems, there are other methods by which sensing of hazard bridge deck conditions could be achieved.

The vehicle speed traps at Prosser Creek provided more reliable data relative to roadway conditions than any of the roadway sensors. This information coupled with some weather measurements and deck temperature measurements could produce highly reliable hazard sensing.

About the least expensive motorist warning system is a simple thermistor and a sign relating the roadway temperature or freezing condition. It should be noted that a threshold setting of 36° on the single bridge deck thermistor at the Prosser Creek site would have triggered a "bridge freezing sign" covering all fourteen hazardous bridge events with 99% accuracy. One hundred percent accuracy could probably have been achieved with several thermistors. The single thermistor and its 36° threshold setting would have missed the early portion of event #2 and the terminal portion of event #8 (Ref. Table 7). The thermistor activated "Bridge Freezing Sign" would have been on and off once each day except for March 21st and 22nd where it would have been all day, overlapping the multi-day event #5. There would have been twenty-six sign on events, fourteen overlapping the fourteen hazardous bridge events and twelve which did not overlap hazardous bridge events. Of these twelve, none can be considered false alarms since the bridge deck was in fact freezing.

The 36° threshold setting rather than 32° (freezing) is likely due to multiple reasons:

1) This thermistor was not located at the coldest point in the bridge deck surface area.

2) There is a temperature gradient between the surface and the location of the thermistor, below the surface.

3) There is a temperature difference between the bridge deck surface and the epoxy in which the thermistor was embedded.

For an area in which frost or ice resulting from a rain-caused wet road is the major skidding hazard on a bridge deck, the multiple thermistor sensor system with activated bridge deck freezing signs would seem to be a highly effective system. Advance warning signs indicate that the bridge can contain frost or ice when freezing. A totally obliterated message would be desirable when the bridge was not freezing.

APPENDIX B

SENSOR SYSTEM CALIBRATION TEST METHODOLOGY AND RESULTS

MBAssociates conducted extensive sensor system calibration testing during the summer of 1974. The details of the test procedures and the results of these tests for each of the sensors is presented in this appendix.

Cytronics System Tests

The Cytronics System consists of a controller and three separate heads or sensors embedded in the roadway. Each thirty minutes a single head is heated while the controller searches the sensor response for the latent heat of fusion due to the occurrence of frost, snow or ice. The heating of the sensor heads is alternated between each of the three independent heads, meaning a specific head is examined every ninety minutes.

As was previously stated testing was minimal on the Cytronics system. Testing in the temperature and humidity chamber revealed controller sensitivity with low temperatures. The heads were tested in the temperature and humidity chamber. Under controlled environmental conditions the heads reacted in unpredictable fashion. A test was conducted of the thermocouple probe voltage output as a function of input temperature, $0^{o}F$ - $70^{o}F$. Minimal voltages were observed to occur at $40^{o}F$ on all heads. The functional plots were similar but of slightly differing values for each head. Due to lack of detailed knowledge of the system and therefore the utility or meaning of these functions, they are not included.

SSI System Tests

The SSI System consists of a controller, a sensor head or witness plate and an amplifier. The amplifier is serially connected between the witness plate and the controller and can be considered part of the sensor circuitry. Both the witness plate and amplifier are embedded in the roadway. Following completion of the first winter testing the SSI controllers were returned to the manufacturer for checkout. The controllers were then returned to MBA for the laboratory testing program. A few tests were run on both the controllers and sensor heads.

A primary input to the SSI controller is referred to as the C_2 signal which is gated at three increasing voltage levels to discern, based on this input, the difference between wet, alert and icy conditions.

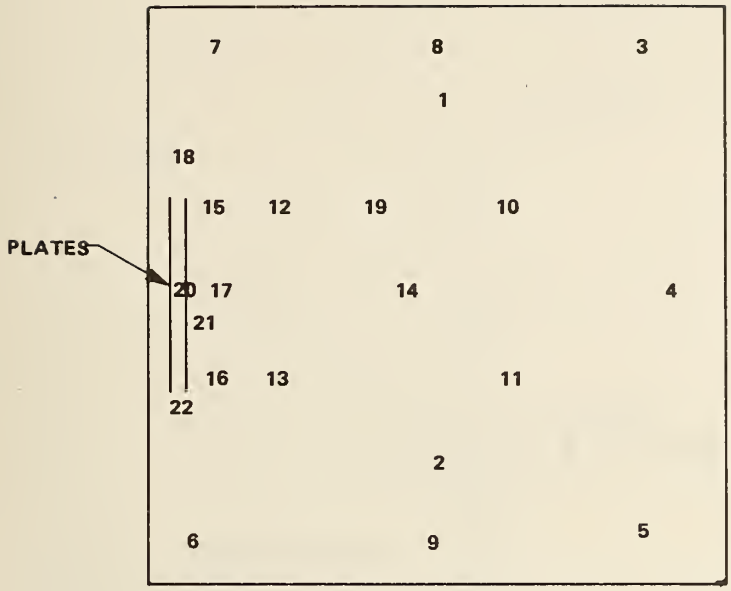
A sensor head or witness plate sensitivity test was conducted by dropping a single drop of salt solution, slush and ice at various locations on the sensor head and monitoring the C_2 voltage response at each location. It was thought that this information would be of use in calibration. The results of this test are depicted in Figure B-1.

A series of tests were run with SSI sensors in the T&H chamber with the controller output status monitored by a strip chart recorder. Over these tests the temperature was varied from $+40^{\circ}F$ to $-10^{\circ}F$ over a 7-hour period under different humidity conditions. A set of recommended calibration values were tested on controller 1031 and sensor 1047 versus a MBA developed set of values. These values are shown in Table B-1. Corresponding readings were made at various monitor points of both controllers for Dry Alarm, Wet Alarm and Ice Alarm conditions. These read-out voltage readings appear in Table B-2.

The results of the two comparison tests of calibration values in Table B-1 found that the 1031 controller went to an ice condition too early, approximately $36^{\circ}F$. The values on controller 1030 produced an alarm which occurred at a T&H chamber temperature of about 32°.

SSI Sensor 1051

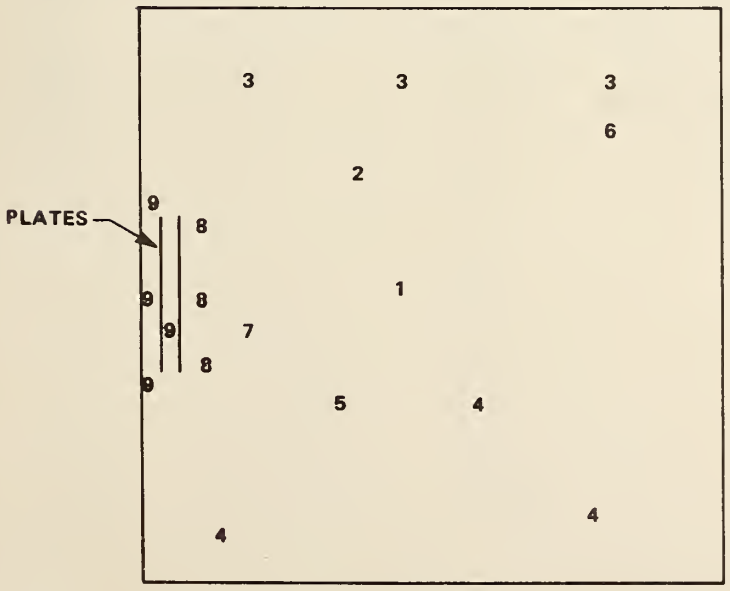
Test Conducted At +20° F



Salt Slush Solution		Drop Of Ice	
Location	C_2 Signal (Volts)	Location	C_2 Signal (Volts)
1	.132	20	.631
2	.162	21	.477
3	NC	22	.655
4	NC		
5	NC		
6	NC		
7	NC		
8	NC		
9	.151		
10	.179		
11	.206		
12	.233		
13	.267		
14	.315		
15	.325		
16	.328		
17	.349		
18	NC		
19	.691		
20	.655		
21	.513		
22	.649		

SSI Sensor 1051

Test Conducted At +65° F



1 Drop of Salt Solution

Location	C_2 Signal (Volts)
1	.103
2	.078
3	.026
4	.267
5	.302
6	.298
7	.439
8	.913
9	.941

FIGURE B-1
SSI SENSOR SENSITIVITY TESTS

TABLE B-1
CONTROLLER CALIBRATION

RECOMMENDED SETTING		MBA DEVELOPED SETTINGS
Controller		**Controller**
1031		**1030**
56K	Salt Composition Resistor	56K
.90v	Salt Composition Level	.90v
1.68v	Salt Comp TP[1]	1.256v
.30v	Prep Level C_2	.30v
.85v	Wet/Ice Level	.90v
.75v	Prep/Alert Level	.65v
33.5KΩ	Interlock Ω	37KΩ

TABLE B-2

SSI CONTROLLER MONITOR

POINT VOLTAGES
(VOLTS)

CONTROLLER 1031

Dry Alarm		°R/O	Wet Alarm R/O	Ice Alarm R/O
TB_1	Mode	Voltages	Voltages	Voltages
1-1	Temp	-3.373	-3.373	-.153
1-2	Wet	0	+60	0
1-3	Alert	0	0	0
1-4	Ice	0	0	+60
1-12	Plated	-3.16	-1.23	-3.57
1-13	C_2 Signal	-.284	.83	.673
1-14	Thermistor	-3.184	-3.184	-3.051
1-15	Thermistor	-1.527	-1.527	-.028
TP_1	Test Point 1	.984	.505	1.007
TP_2	Test Point 2	.194	.489	.162

CONTROLLER 1030

Dry Alarm		R/O	Wet Alarm R/O	Ice Alarm R/O
TB_1	Mode	Voltage	Voltage	Voltage
1-1	Temp	-3.677V	-3.677	-.236
1-2	Wet	0	+6V	0
1-3	Alert	0	0	0
1-4	Ice	0	0	+6V
1-12	Plate 2	-3.1V	-1.61	-3.6
1-13	C_2 Signal	-.012V	-1.06	-1.073
1-14	Thermistor	-3.059	-1.579	-3.219
1-15	Thermistor	-1.579	.975	-.101
TP_1	Test Point 1	.995V	.492	.657
TP_2	Test Point 2	.008V	.607	.709

A subsequent test in a 24-hour ice bath revealed the temperature interlock resistance of 35Kn would calibrate the interlock stage above 32°. Based on MBA laboratory and field testing it is likely that the manufacturer could improve the system calibration values and achieve better laboratory performance.

Holley System Tests

The Holley Sensor System basically consists of three components: a controller, containing the logic circuitry to output, dry, icy or alert condition based on sensor inputs; a stovepipe assembly, consisting of air temperature and humidity sensors; and two road sensors, consisting of heated and unheated heads installed in the pavement.

As previously stated, MBA was supplied with detailed schematics, a calibration procedure, and an operation text for the Holley system. This information permitted MBA to conduct a detailed calibration of the Holley system. To ensure proper operation of each sensor, a new calibration procedure was developed.

Figure B-2 shows the result of the air temperature thermistor calibration (the stovepipe). By examining the graph it can be seen that both units A and B track within ± 100 ohms of each other. There is, however, a differential of 370 ohms between Unit B at 36°F (3370 ohms) and Holley's calibration standard at 36° (3000 ohms). If this differential hadn't been discussed and the calibration compensated, the system would have functioned incorrectly.

The results of the conductivity study done of the road sensors is shown in Figure B-3. Using this graph MBA was able to create a frost detection modification. As the graph shows, minimum resistance is seen when the road sensors are in a very conductive state, e.g., high salt (salt water) and sand concentrate on the road. Conversely frost was defined as almost pure water (low in salt content) and in low amounts, the conductivity of frost was determined to be moderately low. A frost resistance of 10,000 ohms for Holley #1 Unit and 6,000 ohms for

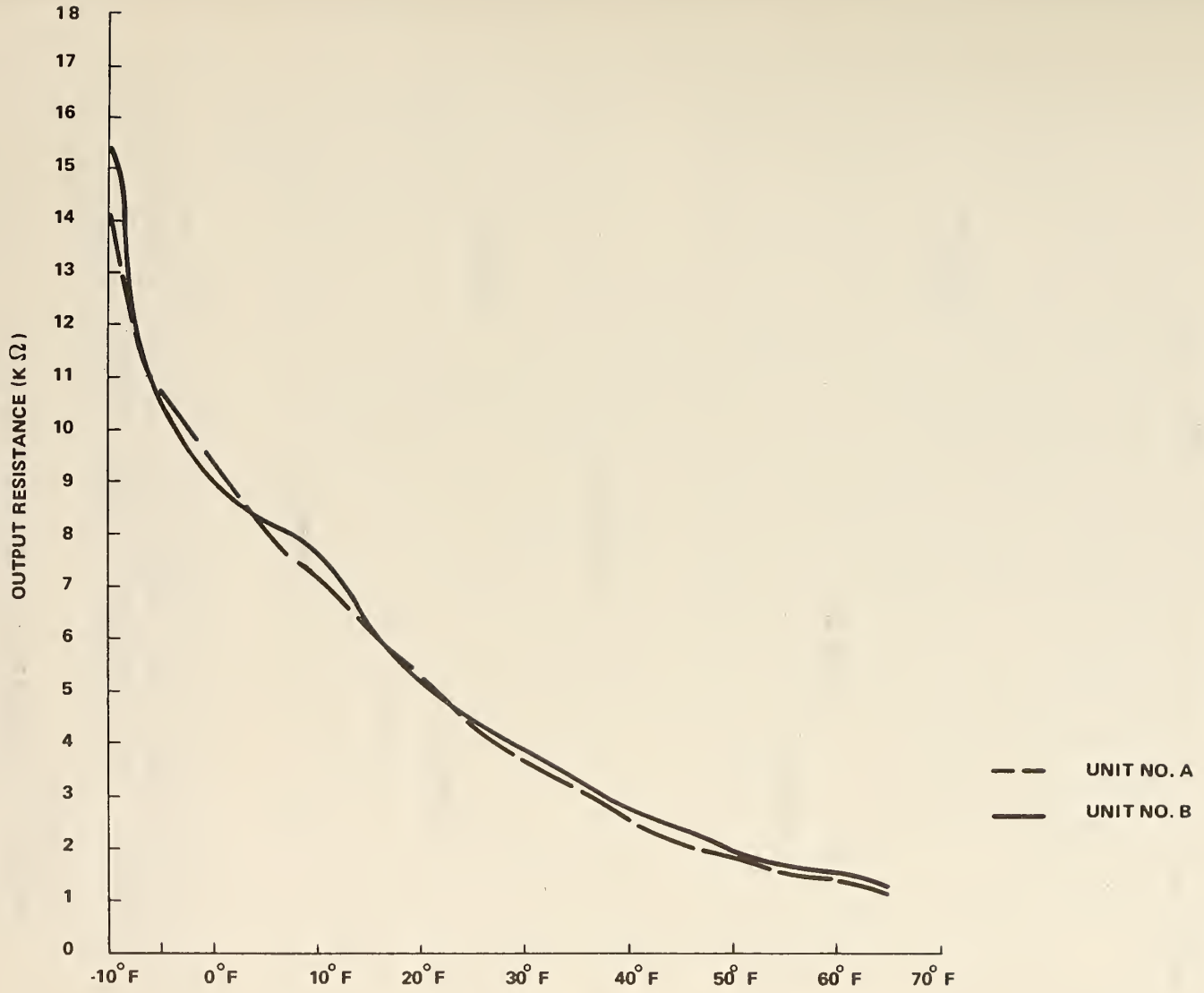


FIGURE B-2
STOVEPIPE AIR TEMPERATURE THERMISTOR TEST
USING S/D 7004 AIR TEMPERATURE -10 +.65° F -3.68K
AIR TEMPERATURE SET 32° +15K

FIGURE B-3
SENSOR 1 – UNHEATED CONDUCTIVITY TESTS

Holley #2 Unit was chosen (these levels should have caused a saturated sensor condition). Examination of Figure B-3 reveals a frost value is approximately identical to 2 or 4 drops of distilled salt solution. This is due to the fact that frost covers more conductive area than does 2 or 4 drops of distilled salt water.

The system was also calibrated for a voltage readout comparison. By recording readout voltages and relating this to the respective sensor condition, translation to sensor status was possible. This was extremely useful while fine tuning the controllers. An example of such a comparison curve is shown in Figure B-4 which was made while water was freezing. At time "A" the sensor is reacting to a water condition, represented by a R/O voltage of 7 to 8 volts (DC), and the dashed line (deck temperature) is reacting to 30°F shown here by its R/O voltage of 4.5 volts (DC). At point "B" the sensor is seeing ice (determined by its 8 to 10 volt output) and the deck sensor temperature is 22°F. This is shown by the 5.25 VDC output. At point "C" the water-ice threshold is seen and this is equivalent to 15,000 ohms, and 7,030 ohms of resistance at the unheated conductivity input.

As stated earlier the controllers were equipped with strip heaters to correct for ambient temperature influence. Figure B-5 shows the temperature effect on the controller. The deck temperature thermistor was replaced with a fixed value resistor, while the controller was subjected to different temperatures and the deck temperature R/O monitored. If the temperature had no effect, the deck temperature R/O voltage would have been constant. However, as the graph shows, once installed the strip heaters proved effective and temperature effect was dropped by 4 + 01, i.e., there is a four volt/60° change.

At conclusion of the testing charts, graphs, and a new calibration procedure was developed. This allowed for fine tuning of both controllers. The final calibration values are listed below.

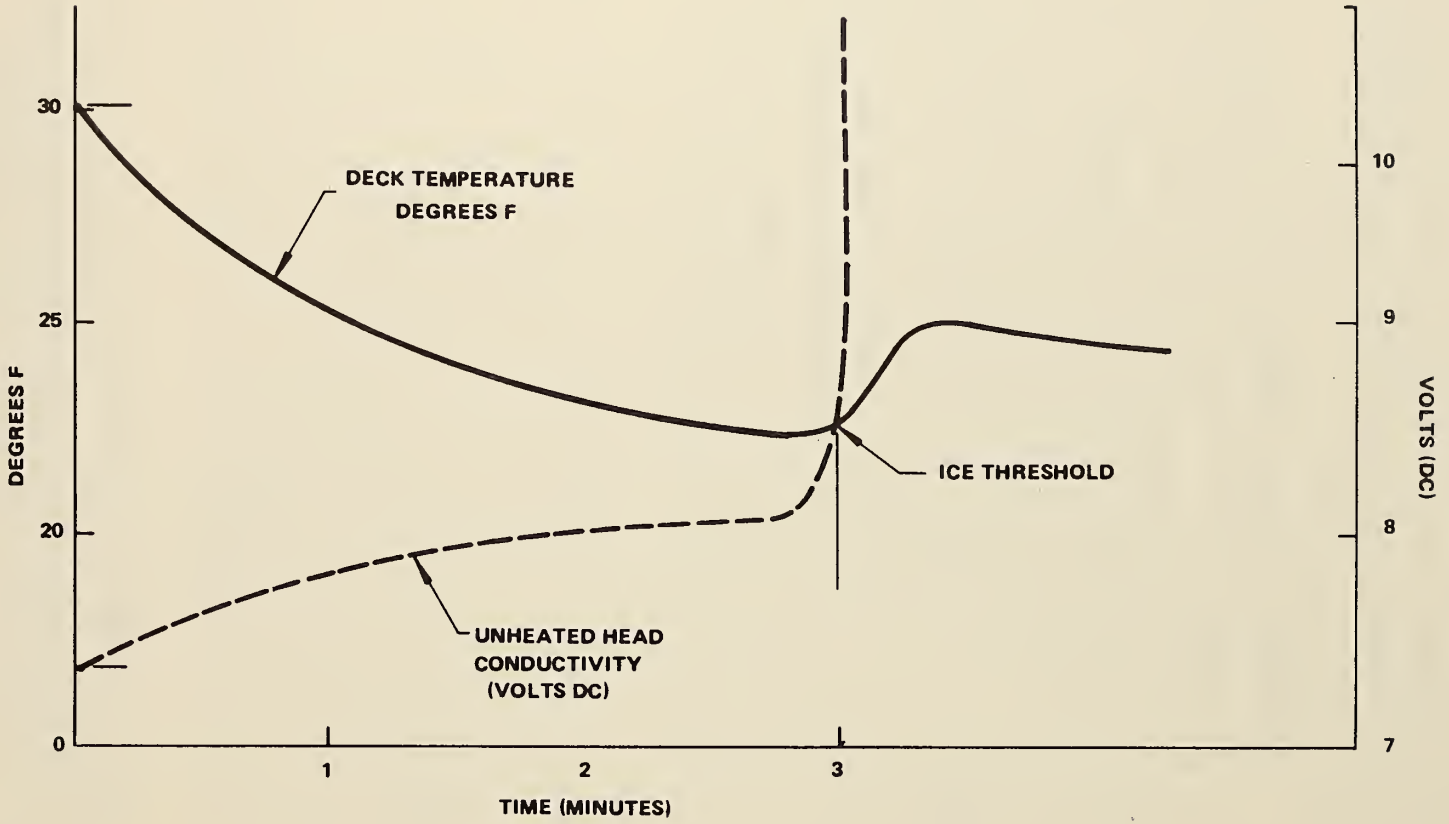


FIGURE B-4
VOLTAGE READOUT/ICE FORMATION CALIBRATION

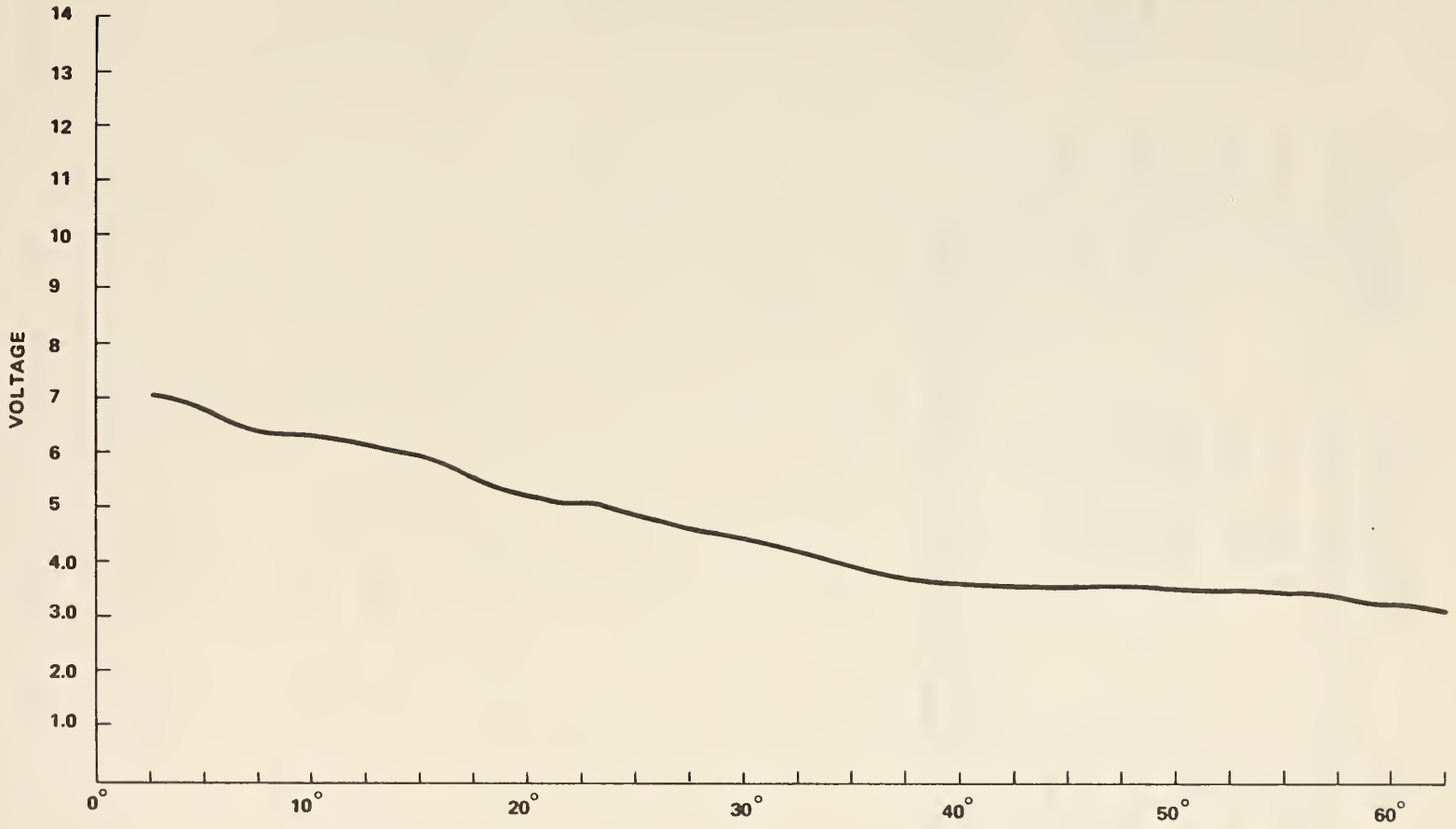


FIGURE B-5
LINEARITY OF UNHEATED DECK SENSE VS. TEMPERTURE

Holley 1 (024)	Holley 2 (025)	Holley's Cal. (Standard)	
3,120 ohms	2,915 ohms	3,300 ohms	Deck Temp
3,059 ohms	3,370 ohms	3,000 ohms	Air Temp
3,000 ohms	3,000 ohms	3,000 ohms	Humidity
2,190 ohms	1,453 ohms	100 ohms	Heated Cond.
15,000 ohms *	7,030 ohms	16,000 ohms	Unheated Cond.
10,000 ohms	6,500 ohms	---	Frost
2,720 ohms	2,530 ohms	2,200 ohms	Heater

* 15,000 ohms is equivalent to ice. This sensor was sluggish, and insensitive as compared to the other sensors.

APPENDIX C

SPEED DATA ANALYSES AND RESULTS

This appendix presents a detailed discussion of the data analyses conducted on the driver behavior (vehicle speed) data collected with particular emphasis on the impact of the hazard warning system

Data from the 1974 test period was compiled and used as a baseline for comparison to the motorist warning experiment data. Attempts were made to identify the salient changes in driver behavior between the two data sets that could be associated with the presence of the warning system. The assumptions made in this analysis are discussed in the main body of this report. The fundamental assumption, however, is that a specific hazard approach speed is a characterization of the driver and the roadway conditions for that data point. The data were reviewed for cases that could be considered as having an influence other than the hazard or the warning sign, e.g., interaction with another vehicle, and these data were removed from the analysis.

Tables C-1 through C-5 present the data summaries for the December 31, 1973 through April 1974 test period. These data were used for the evaluation of the warning sign experiment. Tables C-6 and C-7 present the data for the 1974 base period and the motorist warning experiment classified by speed, vehicle, and day-night categories. The remaining portion of this experiment discusses the comparisons of these two data sets.

Motorist Warning Experiment Analysis

The environmental condition associated with chain controls was chosen for driver speed analysis of the pre-sign comparison period. The data base for this condition was the speed information under those chain control conditions for the period of 1 February 1974 through 30 April 1974. All speed trap data was analyzed as a function of an

MONTHLY PROFILE 12

	CAR						TRUCK					
	DARK			DAYLIGHT			DARK			DAYLIGHT		
	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR
MEAN	36.833333	0.000000	33.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SD	10.70117S	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
N	12	0	1	0	0	0	0	0	0	0	0	0
SUM	442	0.	33.0	0.	0.	0.	0.	0.	0.	0.	0.	0.
SUM2	1.7S4E+04	0.	1.089E+03	0.	0.	0.	0.	0.	0.	0.	0.	0.

COMPOSITES

	CAR				TRUCK			
	CHAINS	SNOW	CLEAR	TOTAL	CHAINS	SNOW	CLEAR	TOTAL
MEAN	36.8333333333	0.0000000000	33.0000000000	36.S38461S385	0.0000000000	0.0000000000	0.0000000000	0.0000000000
SD	10.70117S2399	0.0000000000	0.0000000000	10.3006098898	0.0000000000	0.0000000000	0.0000000000	0.0000000000
N	12	0	1	13	0	0	0	0
SUM	442.00000	0.	33.000000	47S.00000	0.	0.	0.	0.
SUM2	17S40.000	0.	1089.0000	18629.000	0.	0.	0.	0.

SPEED GAPS LESS THAN NINE - 1
INVALID SPEED VALUES - 0
SPEEDS GREATER THAN 85 - 0
SPEEDS LESS THAN 10 - 0

TABLE C-1
COMPOSITE MONTHLY SPEED DATA
1700 - 2400 HOURS DECEMBER 31, 1973

MONTHLY PROFILE 1

	CAR						TRUCK					
	DARK			DAYLIGHT			DARK			DAYLIGHT		
	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR
MEAN	40.000000	56.000000	56.733333	48.857143	0.000000	56.984940	0.000000	74.000000	60.491525	0.000000	0.000000	60.670732
SD	14.605935	3.464102	10.321455	14.229413	0.000000	11.206510	0.000000	0.000000	8.779625	0.000000	0.000000	9.697960
N	4	3	150	7	0	332	0	1	59	0	0	164
SUM	160	168	8.510E+03	342	0.	1.892E+04	0.	74.0	3.569E+03	0.	0.	9.950E+03
SUM2	7.040E+03	9.432E+03	4.987E+05	1.792E+04	0.	1.120E+06	0.	5.476E+03	2.204E+05	0.	0.	6.190E+05

COMPOSITES

	CAR				TRUCK			
	CHAINS	SNOW	CLEAR	TOTAL	CHAINS	SNOW	CLEAR	TOTAL
MEAN	45.6363636364	56.0000000000	56.9066390041	56.6512096774	0.0000000000	74.0000000000	60.6233183857	60.6830357143
SD	14.3336856898	3.4641016151	10.9286857420	11.0914162164	0.0000000000	0.0000000000	9.4445653242	9.4656555341
N	11	3	482	496	0	1	223	224
SUM	502.00000	168.00000	27429.000	28099.000	0.	74.000000	13519.000	13593.000
SUM2	24964.000	9432.0000	1618341.0	1652737.0	0.	5476.0000	839369.00	844845.00

SPEED GAPS LESS THAN NINE - 87
INVALID SPEED VALUES - 7
SPEEDS GREATER THAN 85 - 10
SPEEDS LESS THAN 10 - 7

TABLE C-2
COMPOSITE MONTHLY SPEED DATA — JANUARY 1974

MONTHLY PROFILE 2

	CAR						TRUCK					
	DARK			DAYLIGHT			DARK			DAYLIGHT		
	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR
MEAN	42.384615	54.260870	58.150588	47.309091	58.754386	60.631003	46.428571	65.750000	61.710744	42.473684	59.235294	61.462462
SD	9.520827	9.761787	8.962759	7.915930	9.160556	8.341185	11.480514	19.551215	9.230958	10.329937	9.377851	8.377517
N	26	23	425	55	171	1187	14	4	242	19	102	666
SUM	1.102E+03	1.248E+03	2.471E+04	2.602E+03	1.005E+04	7.197E+04	650	263	1.493E+04	807	6.042E+03	4.093E+04
SUM2	4.897E+04	6.981E+04	1.471E+06	1.265E+05	6.046E+05	4.446E+06	3.189E+04	1.844E+04	9.421E+05	3.620E+04	3.668E+05	2.563E+06

COMPOSITES

	CAR				TRUCK			
	CHAINS	SNOW	CLEAR	TOTAL	CHAINS	SNOW	CLEAR	TOTAL
MEAN	45.7283950617	58.2216494845	59.9770471464	59.1849496555	44.1515151515	59.4811320755	61.5286343612	60.7736389685
SD	8.7163816255	9.3219527720	8.5766037601	9.1299808112	10.8400911323	9.8524651323	8.6087476028	9.3264233498
N	81	194	1612	1887	33	106	908	1047
SUM	3704.0000	11295.000	96683.000	111682.00	1457.0000	6305.0000	55868.000	63630.000
SUM2	175456.00	674385.00	5917263.0	6767104.0	68089.000	385221.00	3504700.0	3958010.0

SPEED GAPS LESS THAN NINE - 327
INVALID SPEED VALUES - 35
SPEEDS GREATER THAN 85 - 31
SPEEDS LESS THAN 10 - 23

TABLE C-3
COMPOSITE MONTHLY SPEED DATA – FEBRUARY 1974

MONTHLY PROFILE 3

	CAR						TRUCK					
	DARK			DAYLIGHT			DARK			DAYLIGHT		
	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR
MEAN	47.489796	54.388889	60.141509	57.679825	61.410714	61.254409	44.777778	53.416667	59.647343	54.710843	61.244186	61.399787
SD	12.366154	9.296818	9.208064	10.482969	8.445195	8.261401	14.945216	9.829994	10.011948	11.816204	8.779570	8.486858
N	49	54	424	228	168	1871	18	12	207	83	86	938
SUM	2.327E+03	2.937E+03	2.550E+04	1.315E+04	1.032E+04	1.146E+05	806	641	1.235E+04	4.541E+03	5.267E+03	5.759E+04
SUM2	1.178E+05	1.643E+05	1.569E+06	7.835E+05	6.455E+05	7.148E+06	3.989E+04	3.530E+04	7.571E+05	2.599E+05	3.291E+05	3.604E+06

COMPOSITES

	CAR				TRUCK			
	CHAINS	SNOW	CLEAR	TOTAL	CHAINS	SNOW	CLEAR	TOTAL
MEAN	55.8772563177	59.7027027027	61.0488017429	60.4291338583	52.9405940594	60.2857142857	61.0829694323	60.4129464286
SD	11.4957185973	9.1509162755	8.4532287802	8.9882062302	12.9250313595	9.2279271332	8.8033646373	9.4439528940
N	277	222	2295	2794	101	98	1145	1344
SUM	15478.000	13254.000	140107.00	168839.00	5347.0000	5908.0000	69940.000	81195.000
SUM2	901342.00	809806.00	8717287.0	10428435	299779.00	364428.00	4360802.0	5025009.0

SPEED GAPS LESS THAN NINE - 405
INVALID SPEED VALUES - 51
SPEEDS GREATER THAN 85 - 57
SPEEDS LESS THAN 10 - 57

TABLE C-4
COMPOSITE MONTHLY SPEED DATA – MARCH 1974

MONTHLY PROFILE 4

	CAR						TRUCK					
	DARK			DAYLIGHT			DARK			DAYLIGHT		
	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR	CHAINS	SNOW	CLEAR
MEAN	50.421053	53.692308	59.338144	58.615764	59.716814	60.535522	49.500000	57.000000	60.410959	59.764706	60.534884	61.331969
SD	8.503200	10.050947	8.413456	8.330807	9.482568	8.416971	12.339639	6.000000	8.769810	9.114721	10.362486	8.337830
N	38	26	485	203	113	3350	16	15	292	68	86	2199
SUM	1.916E+03	1.396E+03	2.878E+04	1.190E+04	6.748E+03	2.028E+05	792	855	1.764E+04	4.064E+03	5.206E+03	1.349E+05
SUM2	9.928E+04	7.748E+04	1.742E+06	7.133E+05	4.130E+05	1.251E+07	4.149E+04	4.924E+04	1.089E+06	2.484E+05	3.243E+05	8.425E+06

COMPOSITES

	CAR				TRUCK			
	CHAINS	SNOW	CLEAR	TOTAL	CHAINS	SNOW	CLEAR	TOTAL
MEAN	57.3236514523	59.5849280576	60.3840938722	60.1499406840	57.8095238095	60.0099009901	61.2240064231	61.0710014948
SD	9.2755851538	9.8436233967	8.4244376756	8.5577458965	10.5367700299	9.8949432030	8.3930312558	8.5483672752
N	241	139	3835	4215	84	101	2491	2676
SUM	13815.000	8144.0000	231573.00	253532.00	4856.0000	6061.0000	152509.00	163426.00
SUM2	812575.00	490520.00	14255455	15558550	289938.00	373511.00	9512615.0	10176064

SPEED GAPS LESS THAN NINE - 951
INVALID SPEED VALUES - 46
SPEEDS GREATER THAN 85 - 71
SPEEDS LESS THAN 10 - 71

TABLE C-5
COMPOSITE MONTHLY SPEED DATA – APRIL 1974

GROUP	VEH.	ILL	MEAN DELTA12	SUM DELTA12	STD.DEV. DELTA12	SUM**2 DELTA12	MEAN DELTA23	SUM DELTA23	STD.DEV. DELTA23	SUM**2 DELTA23	SAMPLE	MEAN TRAP 3	SUM TRAP 3	MINIMUM AT TR-2	MINIMUM AT TR-3
0-20	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
0-20	CAR	DAY	0	0	0	0	0	0	0	0	0	0	0	0	0
0-20	TRUCK	NIGHT	-38.00	-38	.00	1444	-1.00	-1	.00	1	1	46.0000	46	.00	1.00
0-20	TRUCK	DAY	-19.00	-19	.00	361	5.00	5	.00	25	1	38.0000	38	1.00	.00
21-30	CAR	NIGHT	.00	6	3.37	102	2.00	27	5.28	291	10	29.0000	292	.90	.10
21-30	CAR	DAY	1.00	3	1.73	5	.00	0	1.41	2	2	27.0000	54	.50	.50
21-30	TRUCK	NIGHT	.00	-4	2.37	28	.00	-1	2.24	25	6	26.0000	158	.83	.17
21-30	TRUCK	DAY	2.00	5	2.24	13	6.00	13	9.85	169	2	33.0000	66	1.00	.00
31-35	CAR	NIGHT	1.00	7	8.58	225	3.00	12	4.83	106	4	34.0000	139	.75	.25
31-35	CAR	DAY	4.00	25	6.24	291	5.00	35	9.22	575	6	34.0000	208	1.00	.00
31-35	TRUCK	NIGHT	.00	0	3.37	34	-2.00	-9	4.73	83	4	30.0000	120	.50	.50
31-35	TRUCK	DAY	2.00	14	2.65	48	.00	3	1.32	7	5	30.0000	154	.80	.20
36-40	CAR	NIGHT	1.00	11	4.24	115	4.00	29	2.27	143	7	40.0000	283	1.00	.00
36-40	CAR	DAY	1.00	35	6.02	671	3.00	60	4.52	538	19	40.0000	761	.89	.11
36-40	TRUCK	NIGHT	3.00	6	.00	18	.00	-1	2.24	5	2	36.0000	73	.50	.50
36-40	TRUCK	DAY	1.00	15	3.84	111	.00	5	1.96	27	8	37.0000	296	.75	.25
41-45	CAR	NIGHT	.00	28	3.71	412	3.00	98	3.07	562	31	45.0000	1395	.90	.10
41-45	CAR	DAY	8.00	82	12.58	2064	5.00	57	12.75	1713	10	40.0000	408	.80	.20
41-45	TRUCK	NIGHT	3.00	20	3.85	128	.00	-3	2.49	31	6	39.0000	239	.67	.33
41-45	TRUCK	DAY	.00	3	3.23	73	1.00	13	3.64	101	8	44.0000	353	.63	.38
46-50	CAR	NIGHT	3.00	50	4.48	358	4.00	55	6.89	777	13	48.0000	628	.92	.08
46-50	CAR	DAY	5.00	68	12.33	2150	6.00	83	10.74	1851	13	49.0000	637	.92	.08
46-50	TRUCK	NIGHT	-1.00	-1	.00	1	1.00	1	.00	1	1	50.0000	50	1.00	.00
46-50	TRUCK	DAY	.00	-3	7.14	357	4.00	37	15.53	1817	8	53.0000	428	.75	.25
51-55	CAR	NIGHT	9.00	95	14.16	2615	7.00	74	15.03	2524	10	51.0000	510	.90	.10
51-55	CAR	DAY	4.00	126	8.96	2518	2.00	80	6.10	1076	27	51.0000	1395	.85	.15
51-55	TRUCK	NIGHT	1.00	6	2.16	18	1.00	7	3.21	35	4	53.0000	215	.75	.25
51-55	TRUCK	DAY	.00	2	3.33	100	.00	8	2.31	48	10	53.0000	539	.80	.20
56-60	CAR	NIGHT	5.00	63	6.28	669	4.00	48	8.77	946	11	56.0000	618	1.00	.00
56-60	CAR	DAY	5.00	153	4.49	1289	.00	18	10.32	2980	29	53.0000	1550	.90	.10
56-60	TRUCK	NIGHT	4.00	24	5.79	214	1.00	9	2.35	27	5	54.0000	274	1.00	.00
56-60	TRUCK	DAY	3.00	74	4.39	574	.00	-15	11.48	2635	21	53.0000	1133	.86	.14
61-65	CAR	NIGHT	10.00	53	10.55	945	5.00	25	4.12	193	5	57.0000	285	1.00	.00
61-65	CAR	DAY	9.00	212	12.54	5324	6.00	145	10.91	3447	23	59.0000	1373	.96	.04
61-65	TRUCK	NIGHT	13.00	39	16.64	1061	5.00	16	2.35	86	3	55.0000	165	1.00	.00
61-65	TRUCK	DAY	2.00	20	2.92	104	2.00	19	2.15	73	9	62.0000	565	1.00	.00
66-75	CAR	NIGHT	19.00	76	18.49	2470	7.00	28	8.76	426	4	56.0000	225	1.00	.00
66-75	CAR	DAY	6.00	150	8.17	2400	4.00	104	6.10	1240	24	67.0000	1609	1.00	.00
66-75	TRUCK	NIGHT	12.00	50	5.48	666	3.00	13	1.53	43	4	61.0000	246	1.00	.00
66-75	TRUCK	DAY	4.00	56	2.77	300	1.00	17	2.80	107	13	66.0000	870	.77	.23
76+	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
76+	CAR	DAY	7.00	7	.00	49	3.00	3	.00	9	1	73.0000	73	1.00	.00
76+	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
76+	TRUCK	DAY	8.00	25	8.57	339	1.00	3	1.00	5	3	68.0000	205	1.00	.00

TABLE C-6
1974 BASE DATA VEHICLE SPEED ANALYSIS

GROUP	VEH.	ILL	MEAN DELTA12	SUM DELTA12	STD.DEV. DELTA12	SUM**2 DELTA12	MEAN DELTA23	SUM DELTA23	STD.DEV. DELTA23	SUM**2 DELTA23	SAMPLE	MEAN TRAP 3	SUM TRAP 3	MINIMUM AT TR-2	MINIMUM AT TR-3
[illegible]	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	CAR	DAY	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]	TRUCK	DAY	0	0	0	0	0	0	0	0	0	0	0	0	0
21-25	CAR	NIGHT	.00	0	.00	0	4.00	4	.00	16	1	25.0000	25	1.00	.00
21-25	CAR	DAY	-17.00	-17	.00	289	.00	0	.00	0	1	46.0000	46	1.00	.00
21-25	TRUCK	NIGHT	1.00	2	2.83	26	2.00	5	2.24	13	2	24.0000	48	1.00	.00
21-25	TRUCK	DAY	20.00	20	.00	400	9.00	9	.00	81	1	18.0000	18	1.00	.00
31-35	CAR	NIGHT	5.00	11	3.32	61	.00	1	2.24	5	2	28.0000	57	.50	.50
31-35	CAR	DAY	5.00	17	3.61	101	.00	1	2.12	9	3	27.0000	83	.67	.33
31-35	TRUCK	NIGHT	5.00	5	.00	36	5.00	5	.00	25	1	34.0000	34	1.00	.00
31-35	TRUCK	DAY	0	0	0	0	0	0	0	0	0	0	0	0	0
36-40	CAR	NIGHT	14.00	56	11.05	1150	3.00	14	2.16	50	4	28.0000	113	1.00	.00
36-40	CAR	DAY	6.00	46	5.35	424	2.00	14	6.35	270	7	33.0000	231	.57	.43
36-40	TRUCK	NIGHT	5.00	11	4.80	73	3.00	6	1.41	20	2	35.0000	71	1.00	.00
36-40	TRUCK	DAY	6.00	33	5.07	283	1.00	6	1.94	20	5	34.0000	170	1.00	.00
41-45	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
41-45	CAR	DAY	9.00	46	6.02	550	.00	2	2.65	28	5	34.0000	173	.40	.60
41-45	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
41-45	TRUCK	DAY	4.00	11	4.96	75	1.00	4	2.35	14	3	39.0000	119	.67	.33
46-50	CAR	NIGHT	25.00	25	.00	625	7.00	7	.00	49	1	32.0000	32	1.00	.00
46-50	CAR	DAY	11.00	153	8.76	2493	.00	10	4.65	260	13	36.0000	480	.69	.31
46-50	TRUCK	NIGHT	14.00	28	2.83	400	6.00	12	7.07	122	2	38.0000	77	1.00	.00
46-50	TRUCK	DAY	12.00	25	6.08	325	-12.00	-24	22.63	800	2	23.0000	46	.50	.50
51-55	CAR	NIGHT	7.00	7	.00	49	13.00	13	.00	169	1	58.0000	58	1.00	.00
51-55	CAR	DAY	9.00	57	5.95	569	-2.00	-25	7.28	517	10	44.0000	443	.50	.50
51-55	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
51-55	TRUCK	DAY	11.00	23	10.34	349	1.00	3	1.73	5	2	42.0000	84	1.00	.00
56-60	CAR	NIGHT	10.00	21	4.58	221	-4.00	-8	2.83	40	2	41.0000	83	.00	1.00
56-60	CAR	DAY	9.00	59	5.85	657	-1.00	-6	3.35	62	6	46.0000	276	.33	.67
56-60	TRUCK	NIGHT	5.00	10	9.90	148	.00	0	2.83	8	2	53.0000	107	.50	.50
56-60	TRUCK	DAY	1.00	1	.00	1	8.00	8	.00	64	1	63.0000	63	1.00	.00
61-65	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
61-65	CAR	DAY	3.00	13	3.42	71	2.00	11	2.65	37	4	61.0000	244	1.00	.00
61-65	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
61-65	TRUCK	DAY	7.00	22	4.06	180	.00	-1	2.55	13	3	56.0000	168	.67	.33
66-75	CAR	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
66-75	CAR	DAY	24.00	24	.00	576	-4.00	-4	.00	16	1	38.0000	38	.00	1.00
66-75	TRUCK	NIGHT	0	0	0	0	0	0	0	0	0	0	0	0	0
66-75	TRUCK	DAY	7.00	22	6.89	242	-14.00	-43	32.87	2749	3	46.0000	139	.67	.33
76+	CAR	NIGHT	66.00	66	.00	4356	14.00	14	.00	196	1	42.0000	42	1.00	.00
76+	CAR	DAY	46.00	46	.00	2116	2.00	2	.00	4	1	41.0000	41	1.00	.00
76+	TRUCK	NIGHT	50.00	50	.00	2500	-1.00	-1	.00	1	1	39.0000	39	.00	1.00
76+	TRUCK	DAY	11.00	11	.00	121	10.00	10	.00	100	1	75.0000	75	1.00	.00

TABLE C-7
1975 MOTORIST WARNING SYSTEMS TESTS
VEHICLE SPEED ANALYSIS

initial speed category defined by the Trap 1 speed. All data with vehicle gaps less than nine seconds were discarded. In addition all speeds of 5 mph or less at any of the three traps were also discarded. There were 11 speed categories defined which are presented under the "group" column of Table C-6. Speed categories were defined between cars and trucks as well as day and night driving conditions. Both the sample mean and standard deviation is listed for each category and trap number along with the sample size. Table C-6 served as a data base for comparison with the speed data collected during the 1975 motorist warning sign test.

The data base for the sign test was extracted from those conditions where the signs were activated (ON) and SR-89N chain controls were in effect. Of the approximately 350 vehicles observed during the "sign on" condition only 104 vehicles satisfied the additional constraints of chain controls in effect, gaps of nine seconds or more and no trap speeds of 5 mph or less. This data is presented in Table C-7 and despite the small sample size, interesting results were obtained.

Extracting the data from Tables C-6 and C-7, a frequency histogram and cumulative distribution plot of daytime Trap #1 truck speeds are shown in Figure C-1. Despite the sample size there is a clear downward shift in the mean speed between 1974 and 1975. A similar plot of truck night speeds is shown in Figure C-2. This curve shows the same trend, albeit less pronounced than with the car data. Figures C-3 and C-4 present the distributions of daytime and nighttime speeds for cars, respectively, for the comparative data sets from Tables C-6 and C-7. Both graphs show a definite distributional shift downward when the signs are present. The nighttime distributions show lower overall speeds for both sign and no-sign data as compared to the daytime counterpart. This of course is to be expected. Collectively analyzed the mean Trap 1 speeds for cars, daytime and nighttime combined is less under sign control conditions than for no sign data. This is true at the 1%

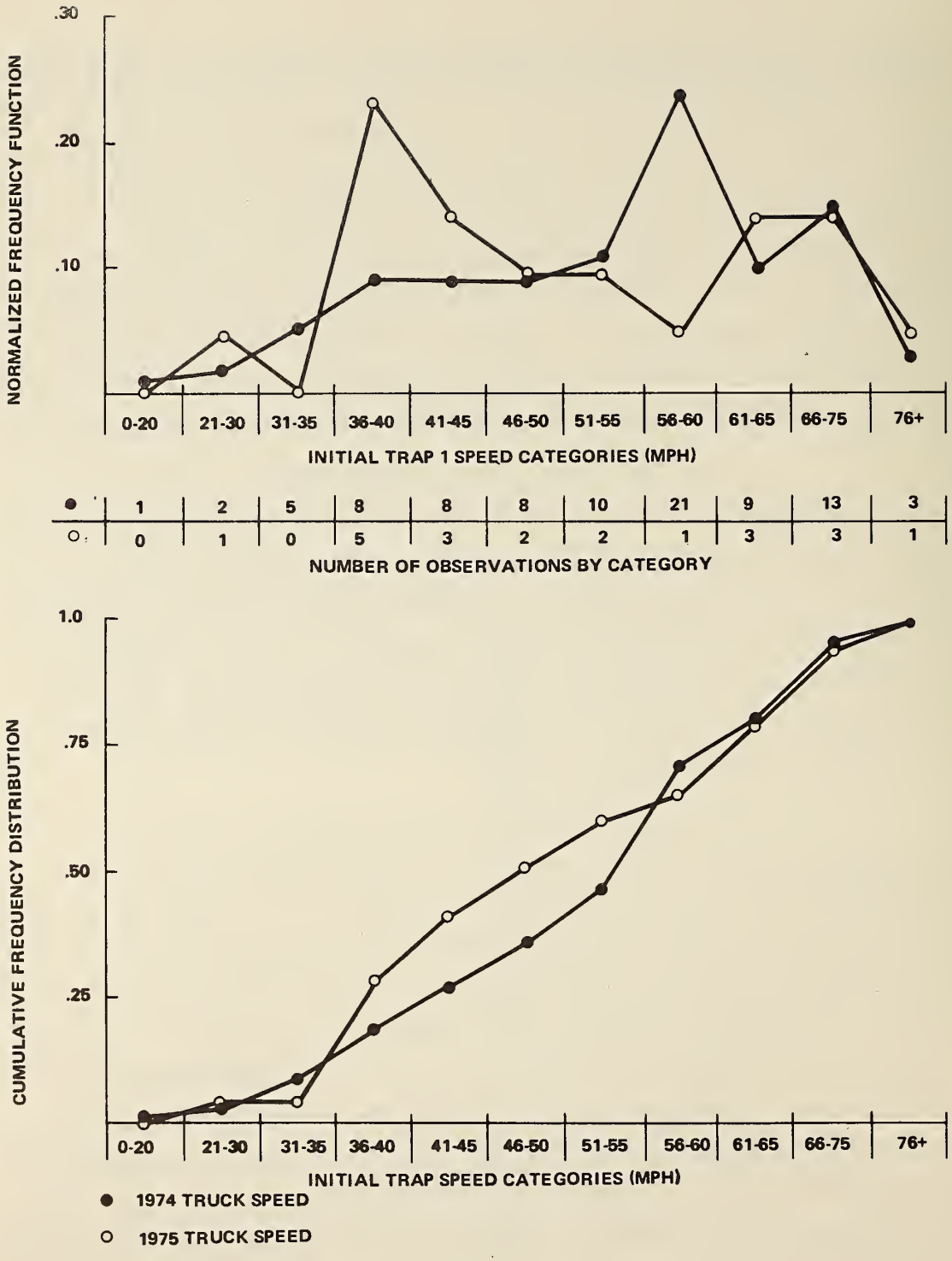


FIGURE C-1
INITIAL TRAP 1 TRUCK SPEED DISTRIBUTION (DAYLIGHT HOURS)

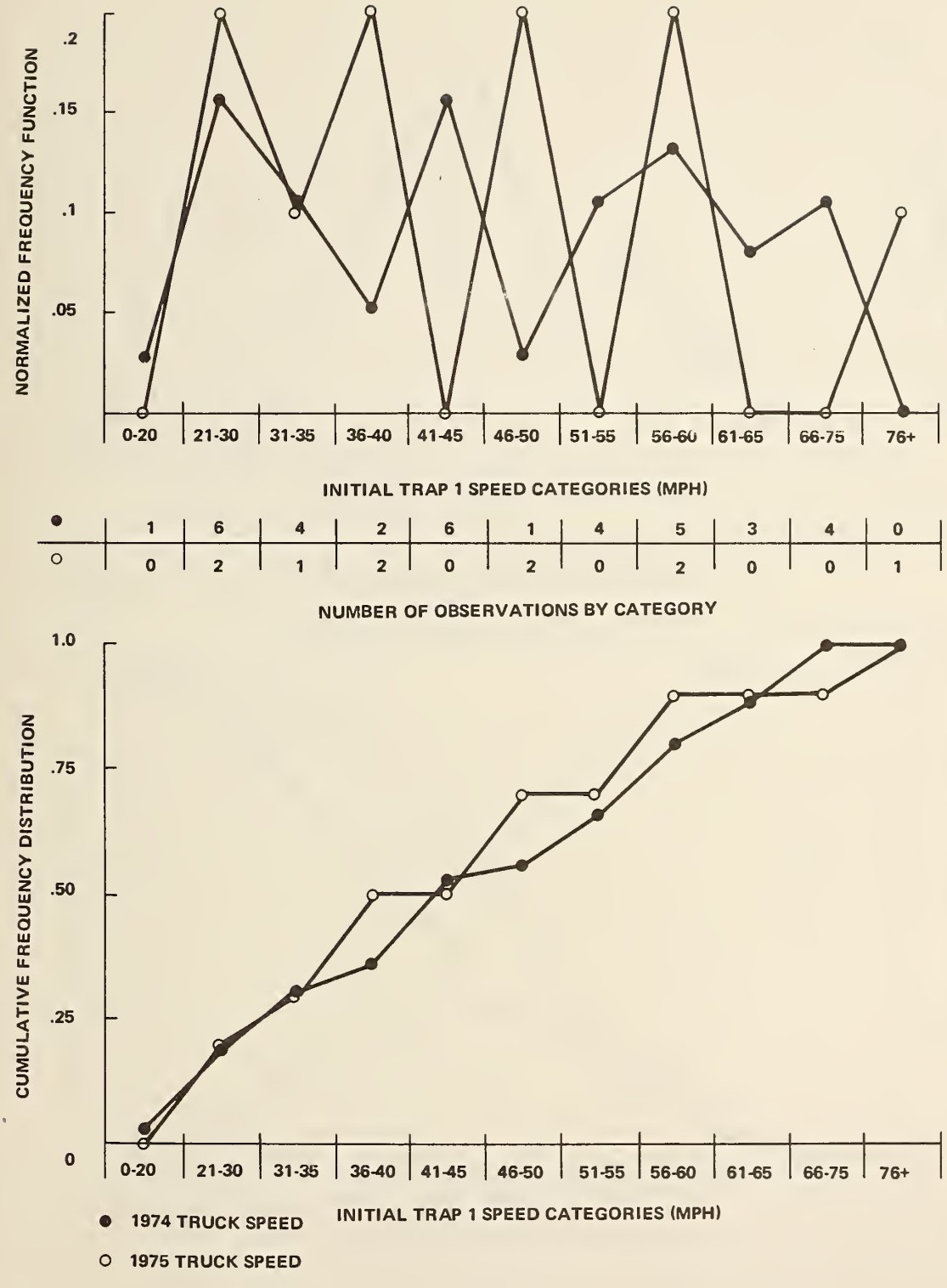
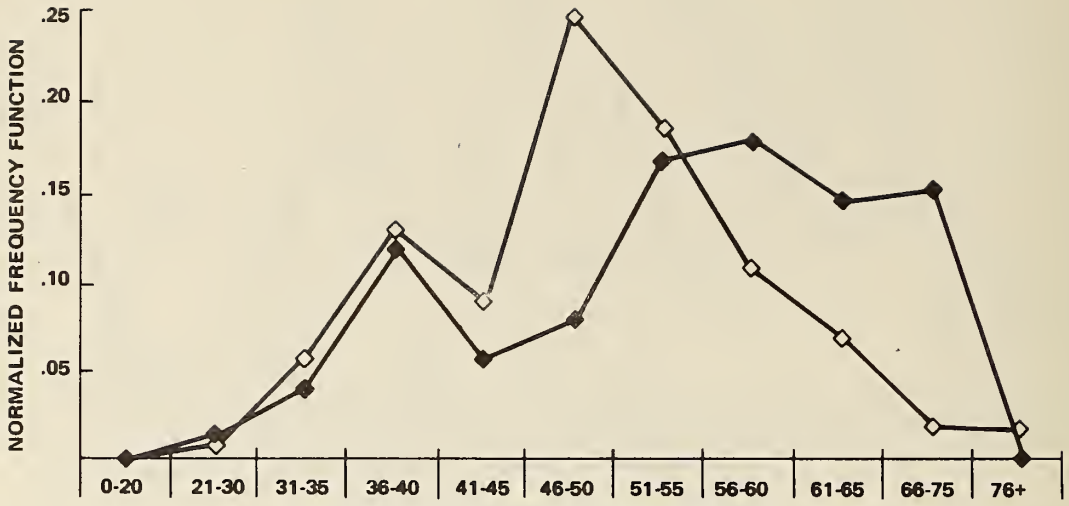
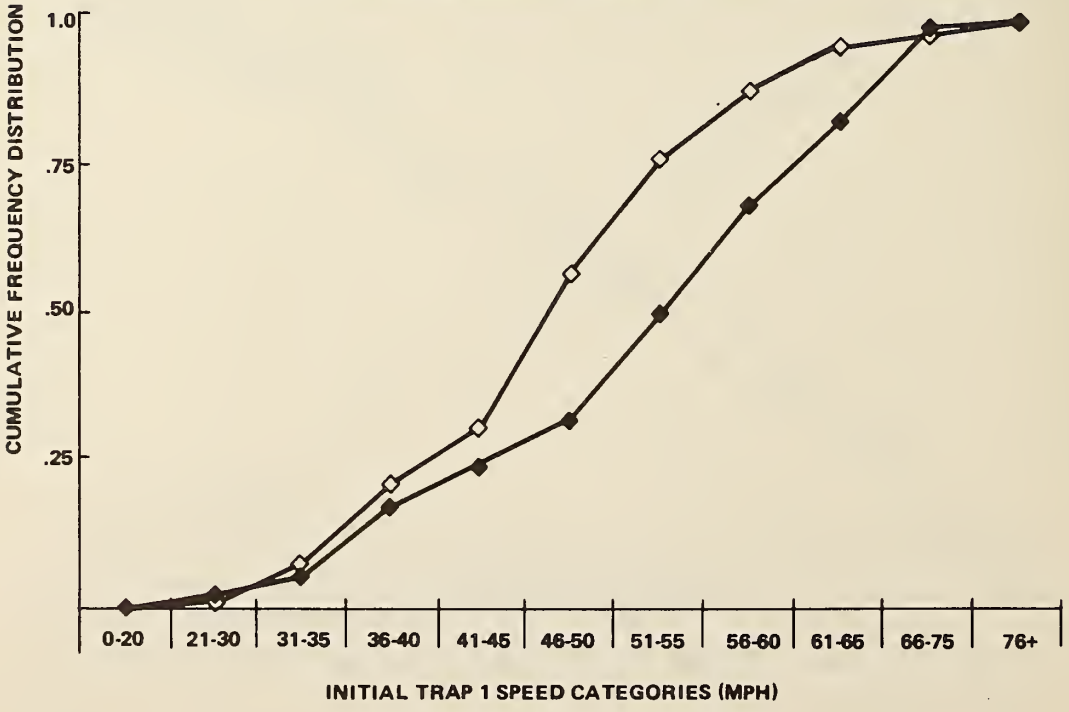


FIGURE C-2
INITIAL TRAP 1 TRUCK SPEED DISTRIBUTION (NIGHT)



◆	0	2	6	19	10	13	27	29	23	24	1
◇	0	1	3	7	5	13	10	6	4	1	1

NUMBER OF OBSERVATIONS BY CATEGORY



◆ 1974 CAR SPEED

◇ 1975 CAR SPEED

FIGURE C-3
INITIAL TRAP 1 CAR SPEED DISTRIBUTION (DAYLIGHT HOURS)

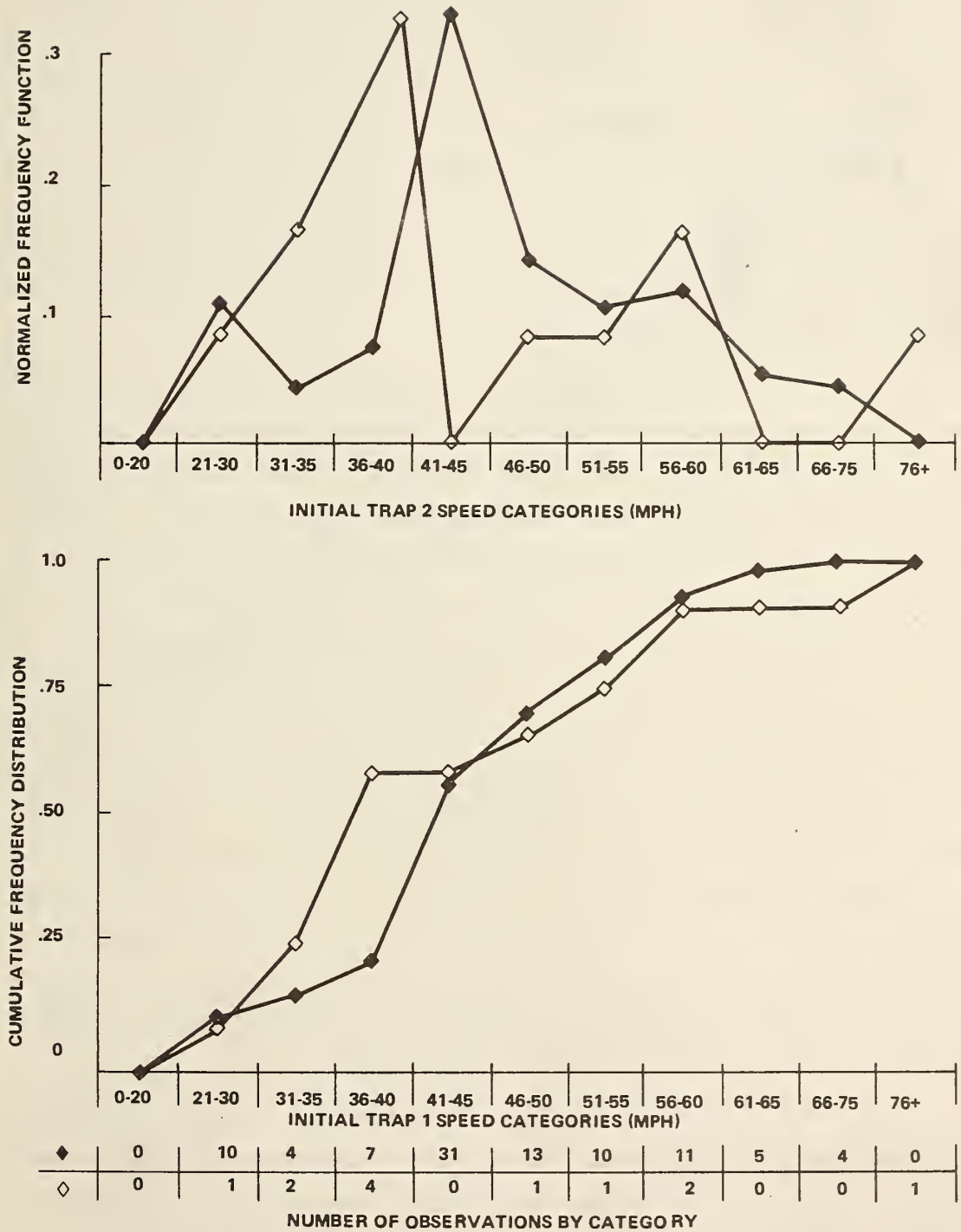
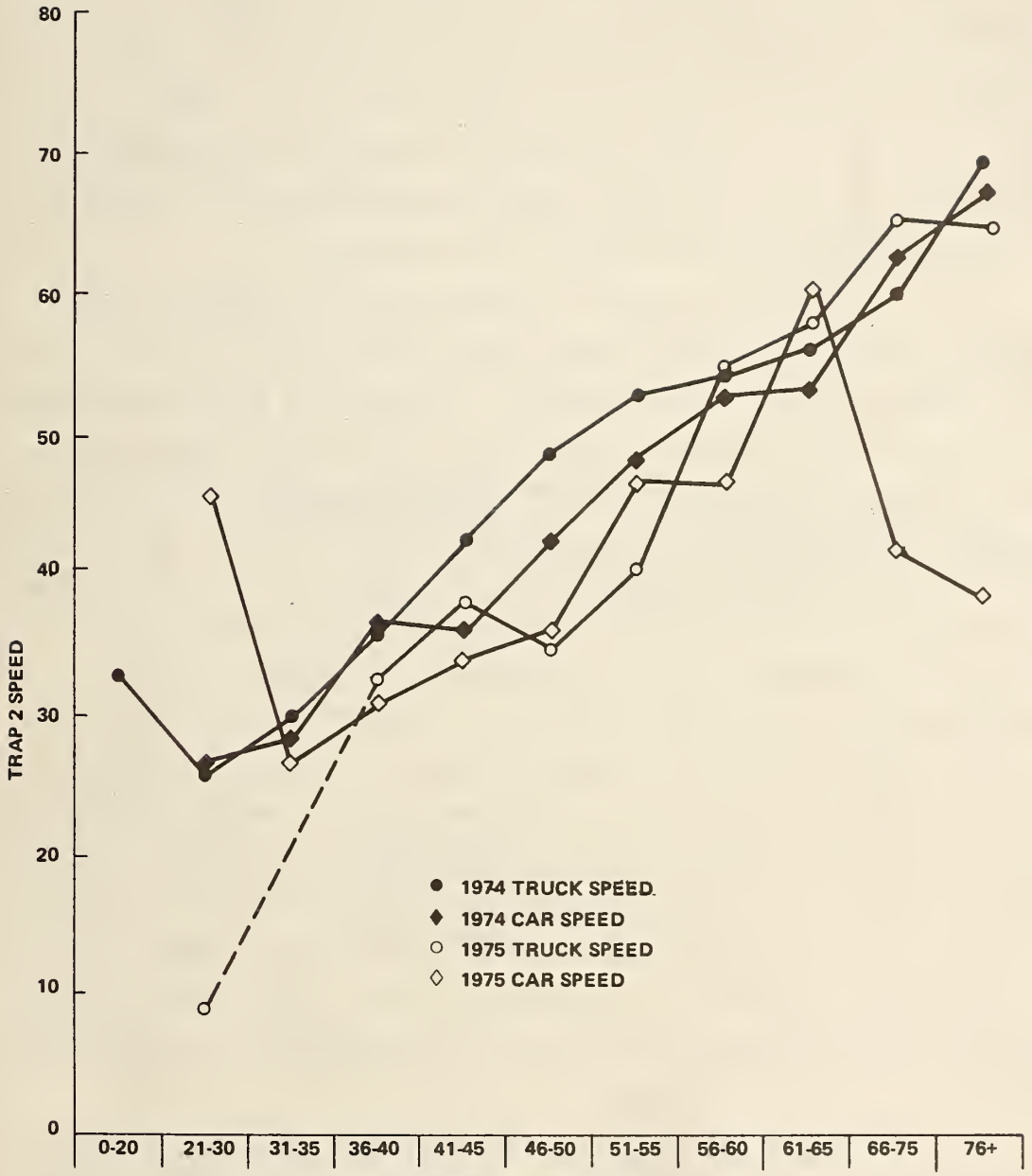


FIGURE C-4
INITIAL TRAP 1 CAR SPEED DISTRIBUTION (NIGHT)

significance level. The same statement is true for trucks at the 1% significance level. A comparison test, 1974 versus 1975 speeds, under clear conditions revealed the opposite for both cars and trucks, i.e., 1975 car (truck) speeds greater than 1974 car (truck) speeds under clear weather conditions at the 1% significance level. In summary it has been shown that insofar as the comparison data sets of Tables C-6 and C-7, Trap 1 speeds were significantly lower for the motorist warning test than the comparative 1974 data base. This is NOT due to the signs but likely due to more roadway snow accumulation in 1975 than in 1974.

To examine the traffic speed impact of the signs it will be necessary to examine the behavior of similarly categorized initial speed (Trap 1) vehicles in terms of their successive speed over Traps 2 and 3. The comparison of traffic data across 1973/1974 roadway conditions indicated that Trap #3 speeds were generally higher than Trap #2 speeds. This is consistent with roadway geometry since the average driver is likely to accelerate somewhere between Traps 2 and 3 in anticipation of the long straight hill on the south side of the bridge. The actual location of the bridge sign is roughly 50 feet south of Speed Trap 2. It was envisioned that even though the bridge was in full view of the vehicle passing over Trap 2 that the imposing amber flashers of this sign may well have caused some further deceleration. In this case it would not only be necessary to analyze the deceleration between Traps 1 and 2, but also the Trap 3 speed relative to the Trap 2 speed. During conduct of the sign test it was repeatedly noted by the observer that car speed was estimated to achieve its minimal value between Speed Traps 2 and 3.

Figure C-5 shows average Trap 2 daytime speeds by vehicle type for initial speed category of the vehicle for both 1974 base data and 1975 sign test data. Except for a few spurious data points, small sample and/or very low or high speed categorization, it can be seen that base data, Trap 2 truck speeds, are higher than these same speeds under the sign test. The same conclusion is generally true for



0-20	21-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-75	76+
INITIAL SPEED SAMPLE SIZES										
0	2	6	19	10	13	21	29	23	24	1
0	1	3	7	5	13	10	6	4	1	1
1	2	5	8	8	8	10	21	9	13	3
0	1	0	5	3	2	2	1	3	3	1

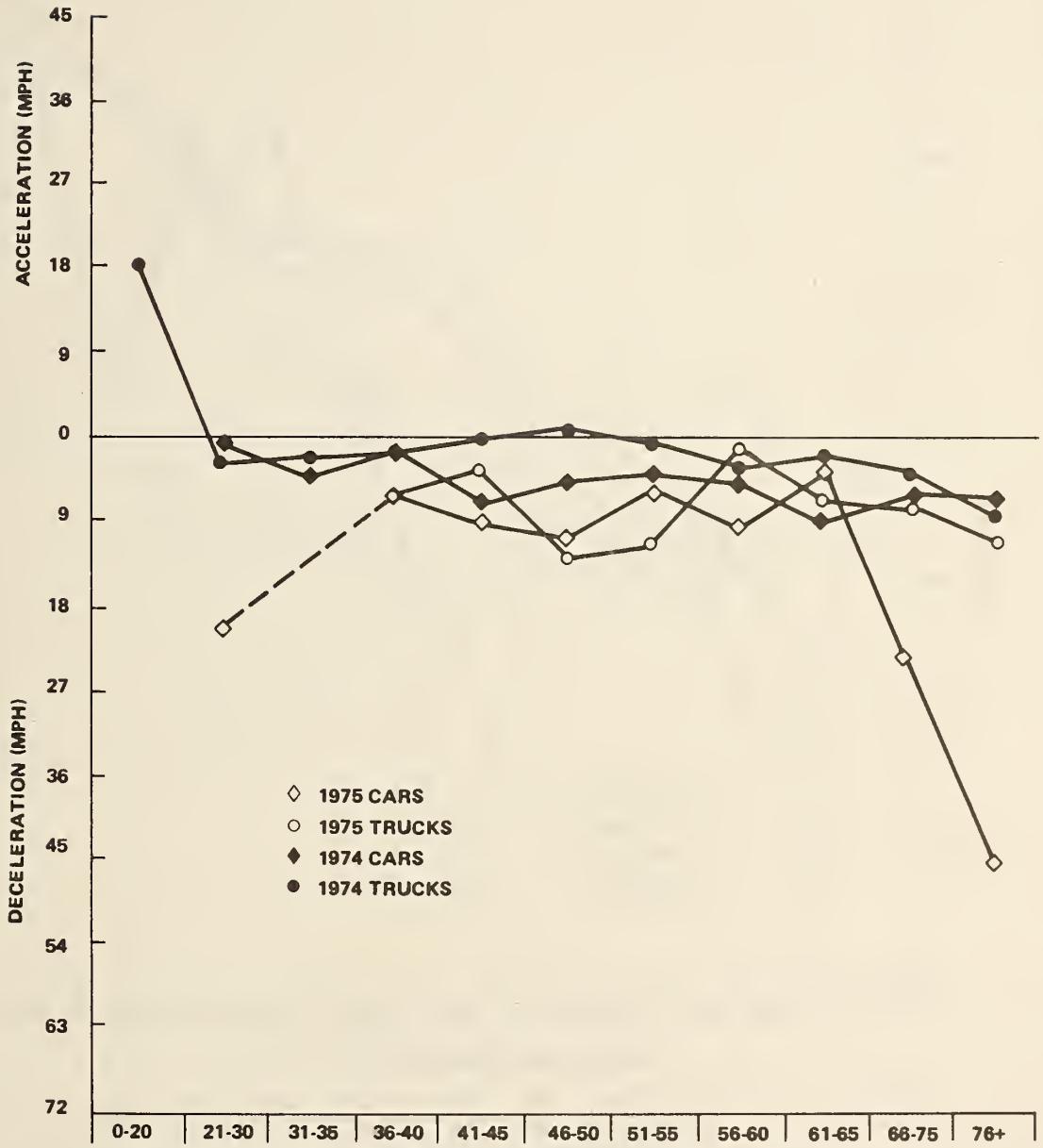
FIGURE C-5
MEAN TRAP 2 SPEEDS (DAYLIGHT HOURS)

car speeds. The same data plotted in terms of average acceleration/deceleration is depicted in Figure C-6. This second figure also shows that within the 30-60 mph category there is almost a universal constant deceleration by vehicle type and by sign or pre-sign condition. Even with a slightly negative slope, increased deceleration with increased initial speed, the amount of increased deceleration per incremental increase in initial speed is smaller than expected.

Figures C-7 and C-8 relate Trap 3 daytime speed behavior. Figure C-7 shows mean Trap 3 speeds for cars and trucks as a function of Trap 1 classification. Except for a few instances the 1975 sign test data indicates lower Trap 3 speeds for both cars and trucks. Figure C-8 displays Trap 2/Trap 3 acceleration/deceleration average for daytime vehicle types. It is clearly seen for the car data that 1974 Trap 2/3 speed differentials bound the 1975 sign test data. Considering only samples of three or greater, this range varies from 1 to 4 mph and is additive with respect to the 4 to 5 mph Trap 1 to Trap 2 increase between the sign test and the 1974 base data. In terms of truck behavior the Trap 2 to Trap 3 results are inconclusive. When the data of Figure C-8 is supplemented by a distributional analysis of percent of vehicle type achieving their minimal speeds at Trap 2, (Figure C-9) it is seen that a greater percentage of high speed trucks decelerate between Traps 2 and 3 under sign operation than under the base 1974 data. Figure C-10 shows that greater percentages of both nighttime and daytime high speed vehicles decelerate between Traps 2 and 3.

Tests for significant deceleration differences in the 1974 base data vs. 1975 sign test data were conducted. These tests were made for samples sizes of three or greater with rejection at the 10% level for base data speeds higher than sign test data. Those speed categories for daytime speeds which were considered significant are tabulated below:

31-35 mph	Car speed (Trap 3)
36-40 mph	Car speed (Traps 2 and 3)



0	2	6	19	10	13	27	29	23	24	1
0	1	3	7	5	13	10	6	4	1	1
1	2	5	8	8	8	10	21	9	13	3
0	1	0	5	3	2	2	1	3	3	1

FIGURE C-6
MEAN SPEED CHANGE BETWEEN TRAP 1 AND TRAP 2 (DAYLIGHT HOURS)

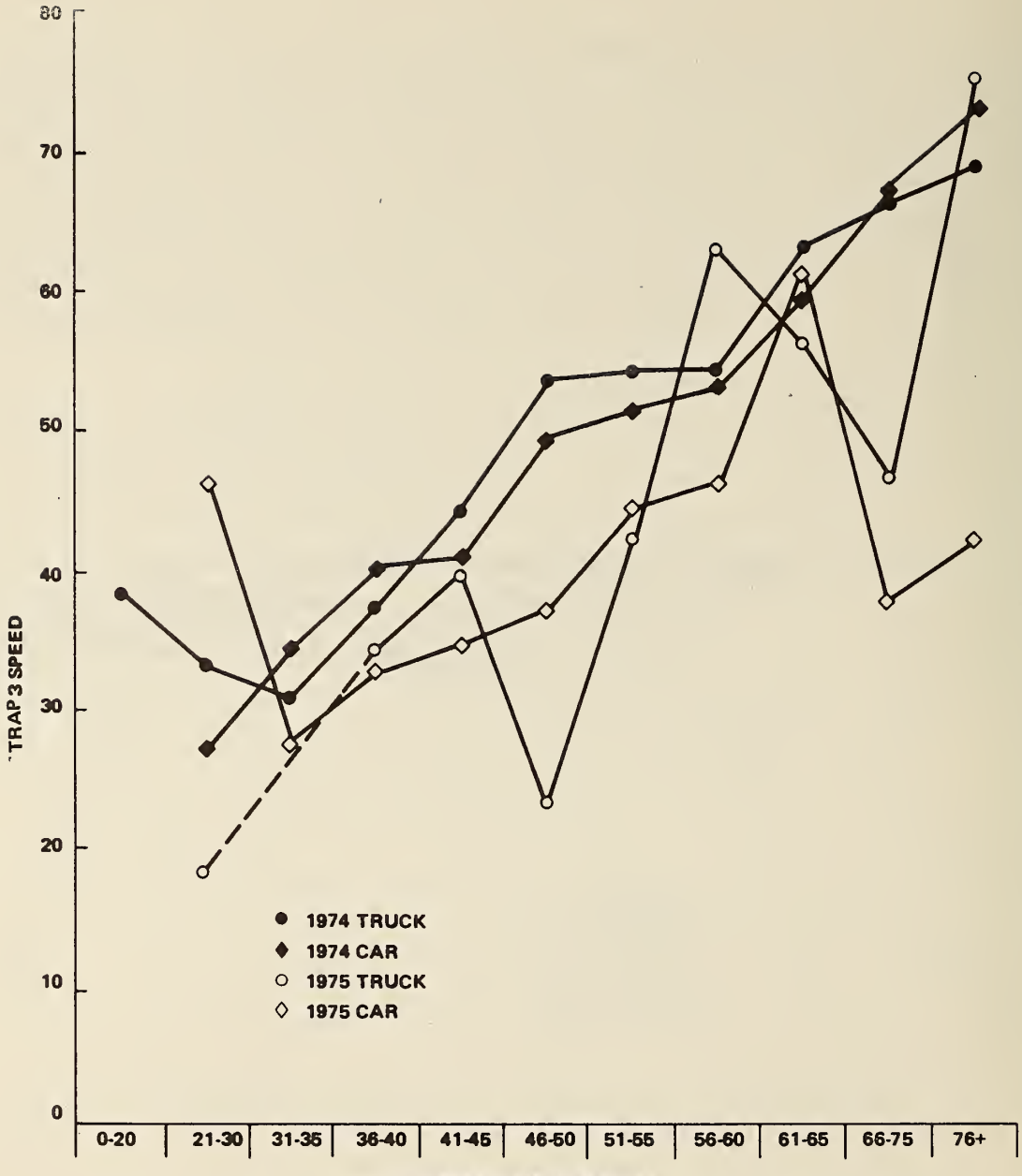


FIGURE C-7
MEAN TRAP 3 SPEEDS (DAYLIGHT HOURS)

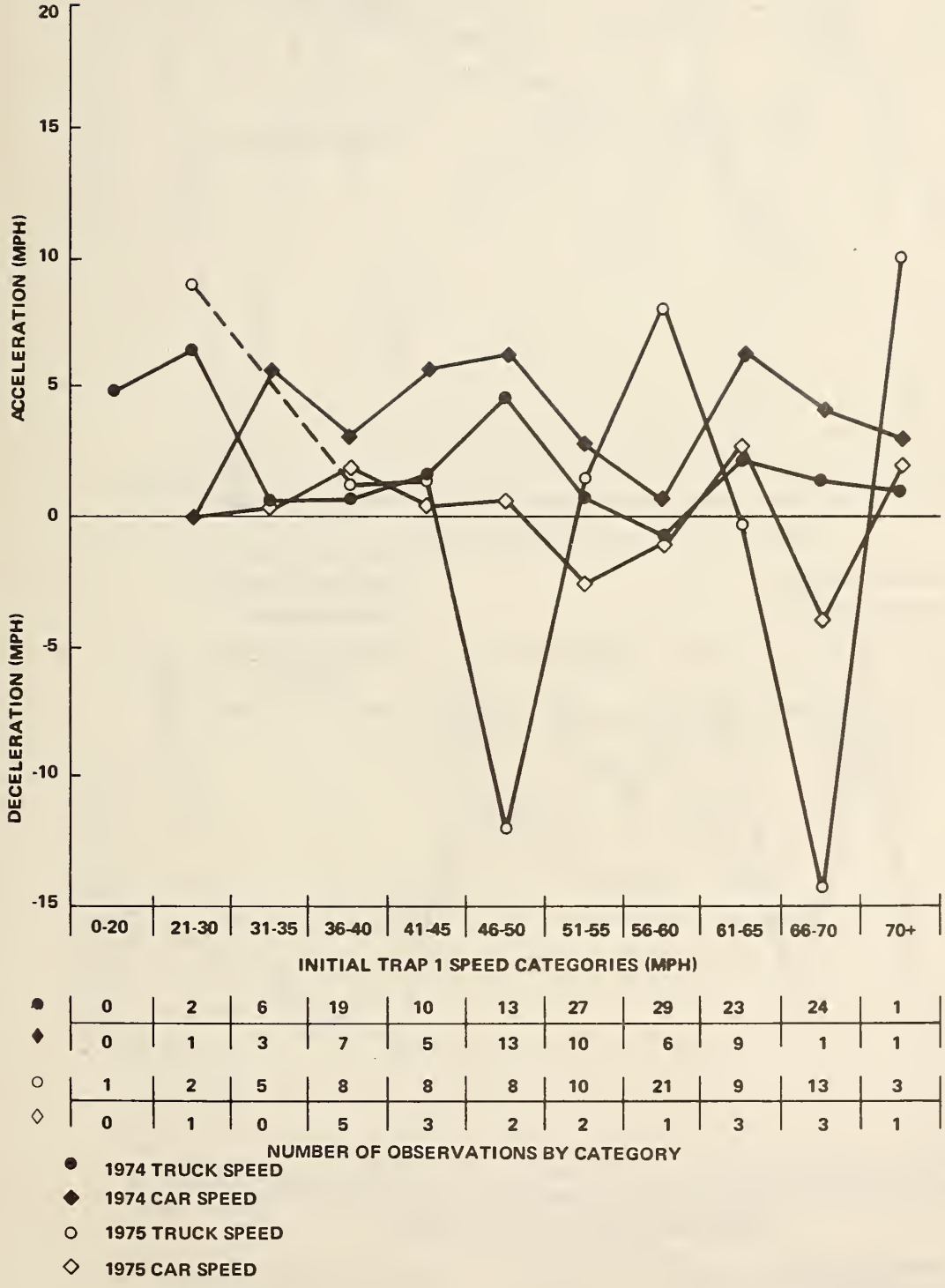
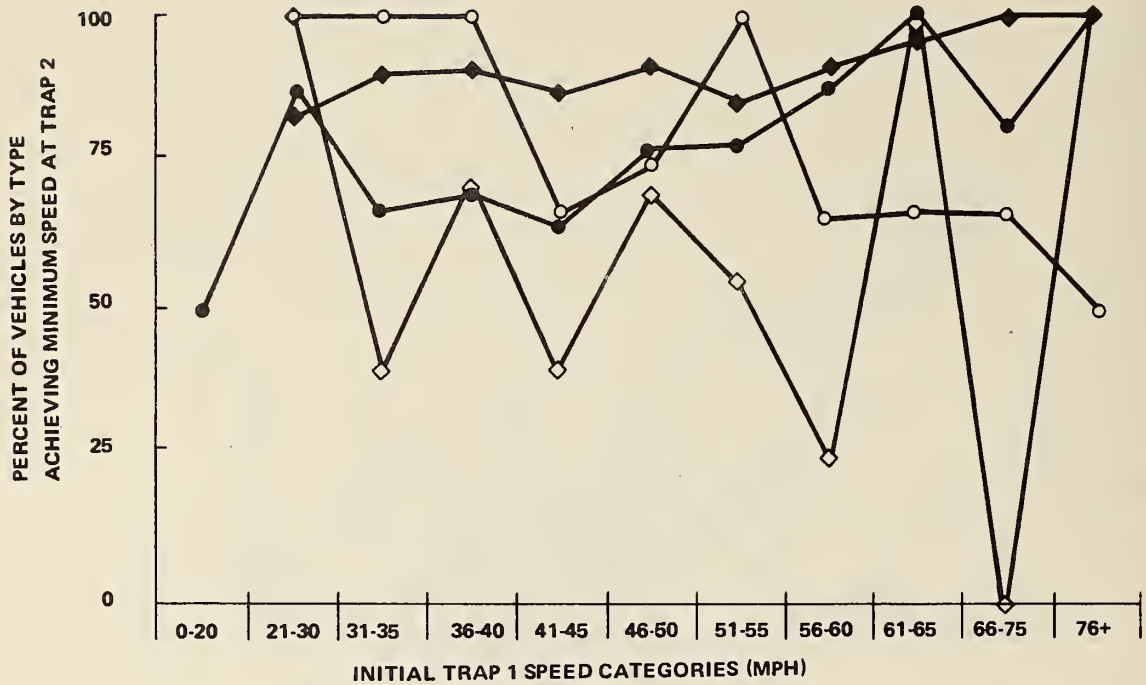


FIGURE C-8
MEAN SPEED CHANGE BETWEEN TRAP 2 AND TRAP 3
(DAYLIGHT HOURS)



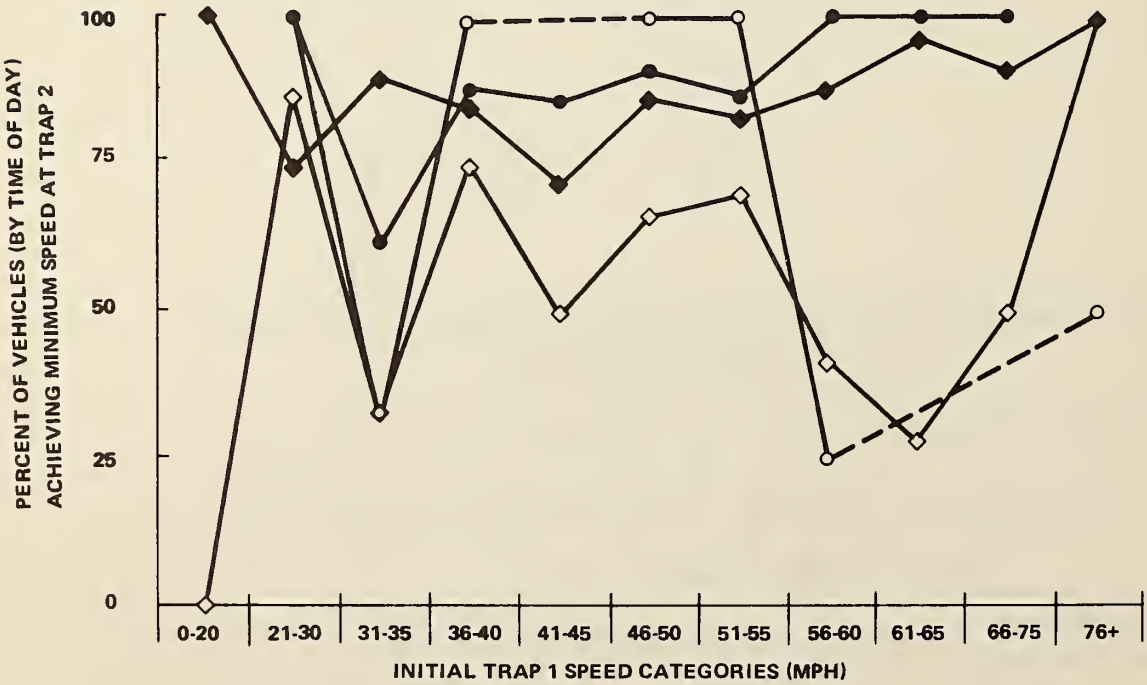
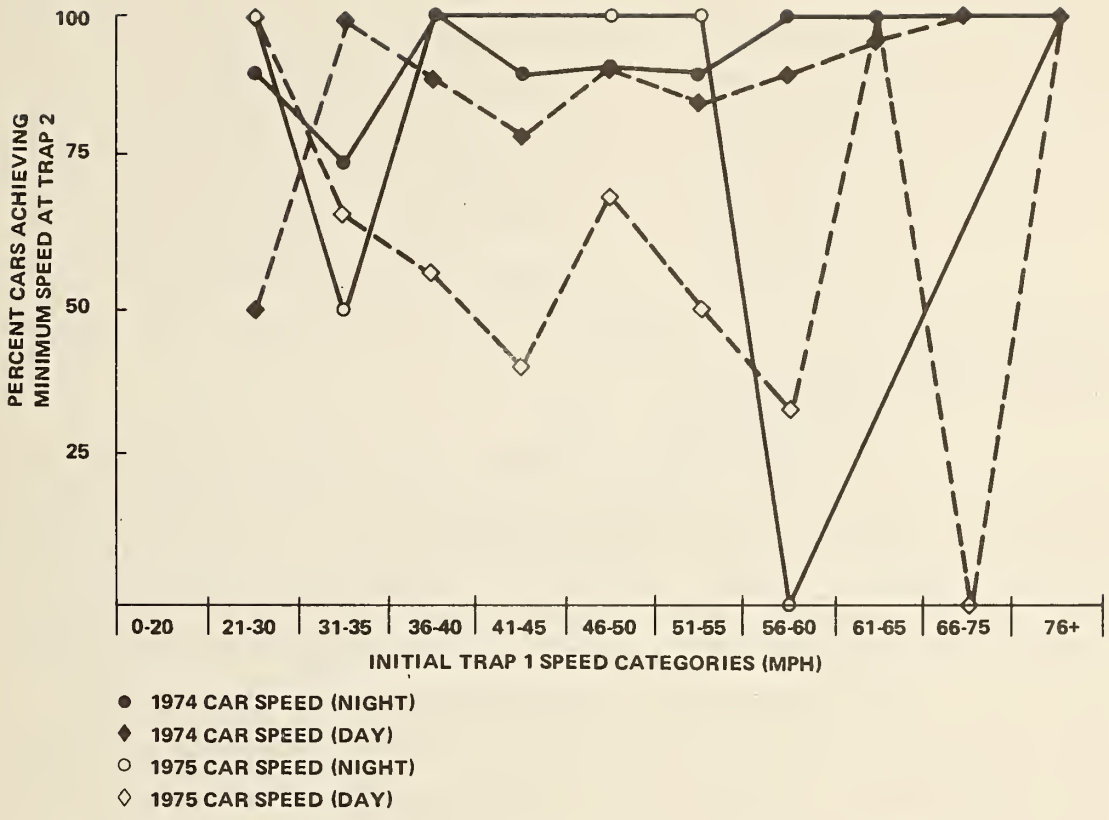


FIGURE C-9
PERCENTAGE OF VEHICLES ATTAINING MINIMUM SPEED AT TRAP 2



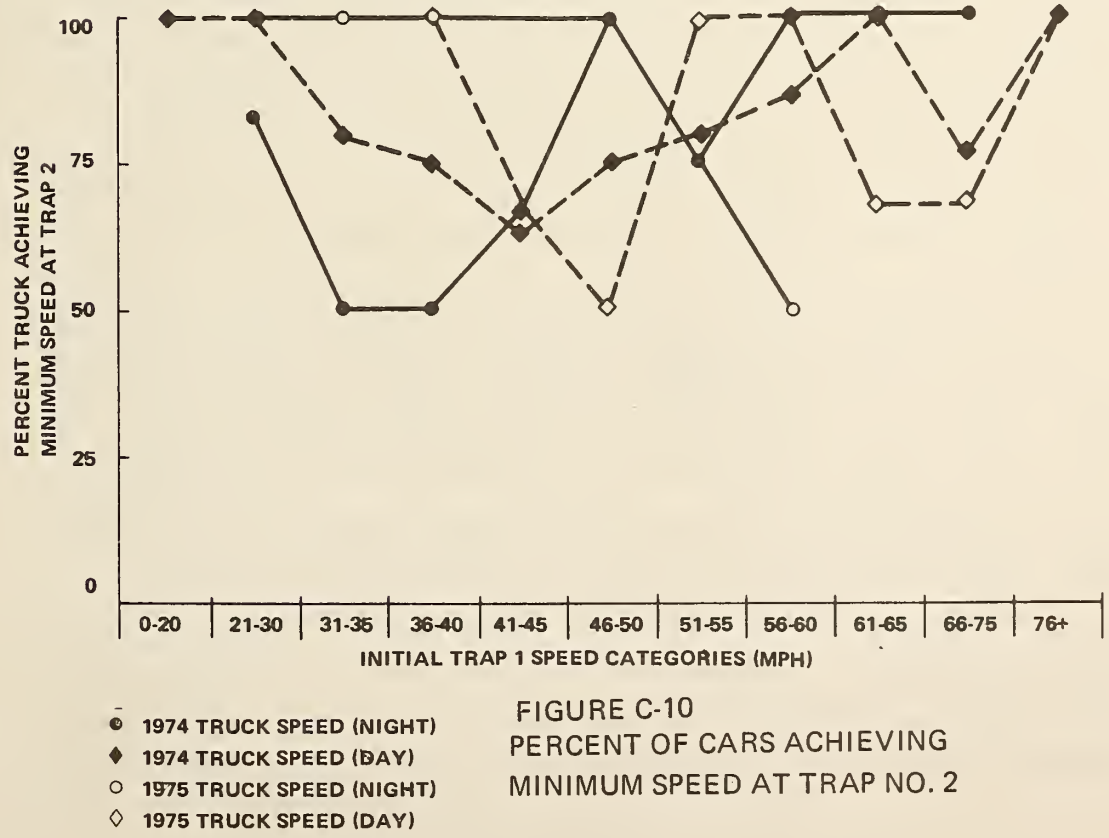


FIGURE C-10
PERCENT OF CARS ACHIEVING
MINIMUM SPEED AT TRAP NO. 2

41-45 mph	Car speed (Traps 2 and 3)
46-50 mph	Car speed (Traps 2 and 3)
51-55 mph	Car speed (Traps 2 and 3)
56-60 mph	Car speed (Traps 2 and 3)
61-65 mph	Truck speed (Traps 2 and 3)
66-75 mph	Truck speed (Traps 2 and 3)

Of the foregoing significant differences at the 10% level, 5 were significant at the 1% level.

Only very small samples sizes of 12 and 10 were obtained for cars and trucks respectively under 1975 nighttime sign activation. Only one initial speed category, cars - 36-40 mph, contained a sample size of three or greater. When this category was tested against similar 1974 base data it proved significant at the 10% level, i.e., both decelerations represented by Trap 2 and Trap 3 speeds were greater than 1974 base car data decelerations over the same initial speed category. Mean Trap 2 night speed is shown in Figure C-11. As in the case for day mean speeds (Figure C-5), comparison is made between base data and the sign operation data for both cars and trucks. Figure C-12 shows the same data for acceleration/deceleration observed at Trap 2 relative to Trap 1 initial speeds. In spite of the small sample size, it is reasonable to conjecture that with increased data and elimination of outlier behavior, e.g., 1974 truck with 9 mph speed at Trap 1 and 47 and 46 mph on Traps 2 and 3 respectively, the decelerations would be statistically significant (higher) at Trap 2 than for the base 1974 data. Figure C-13 depicts mean Trap 3 speeds with car speed comparisons appearing to be more consistently significant than trucks compared over the base data versus motorist warning sign data. This is somewhat clarified by Figure C-14 which plots acceleration/deceleration values between Traps 2 and 3. Higher speed trucks appear to have lower Trap 2 mean speeds during the 1975 sign experiment and predominantly decelerate, in the mean, between Traps 2 and 3. Intermediate and slow speed trucks produce

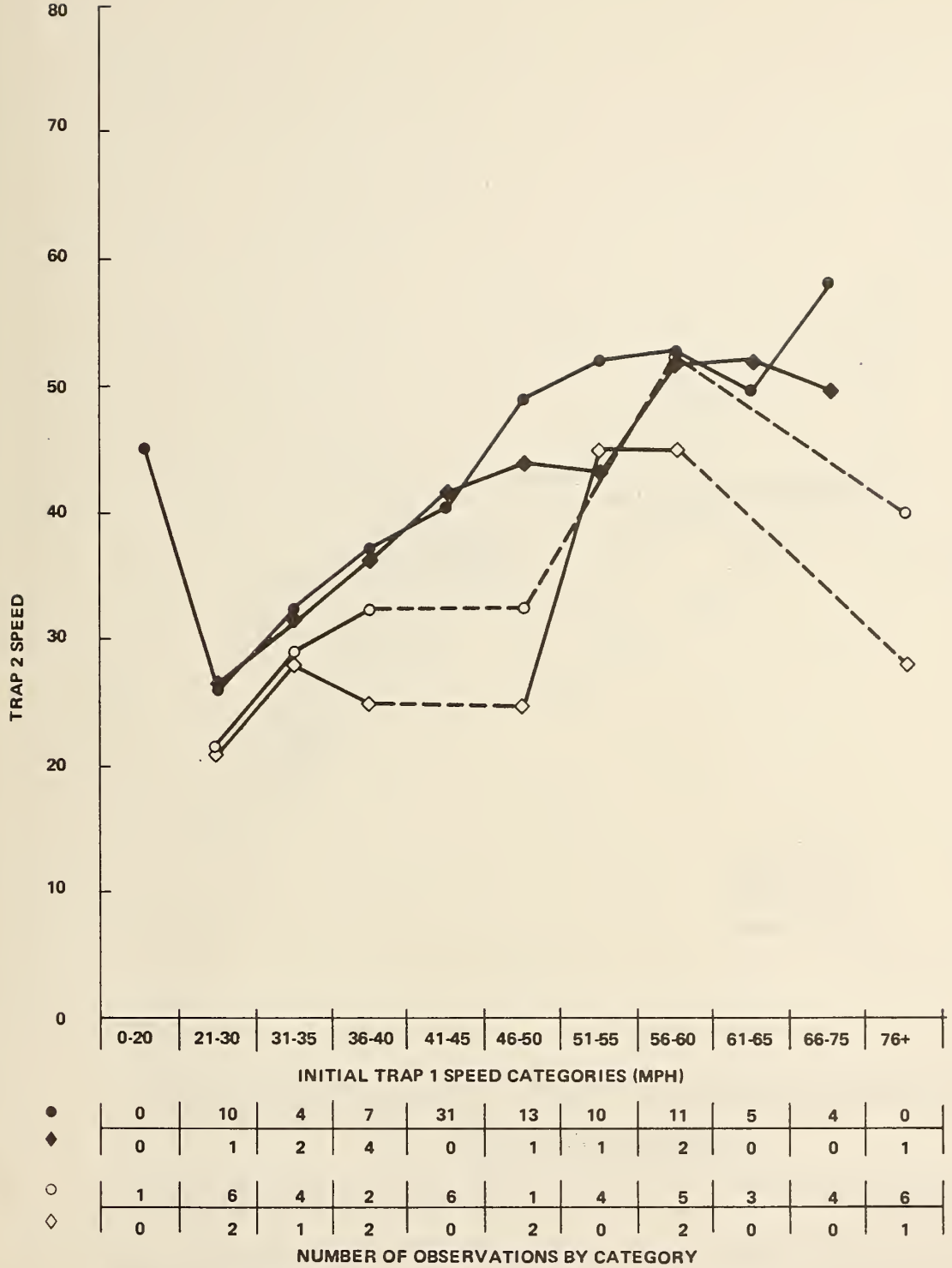
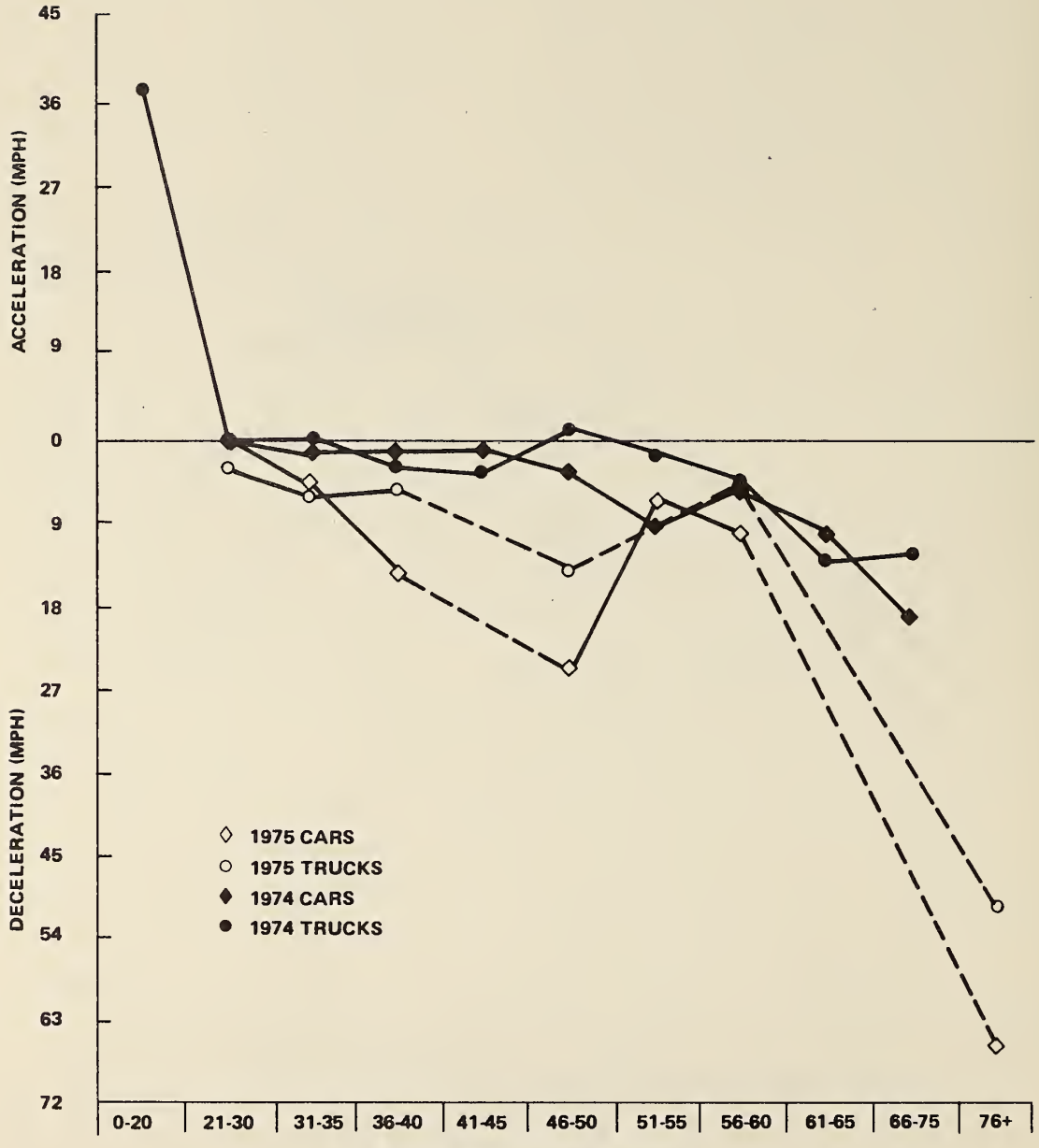
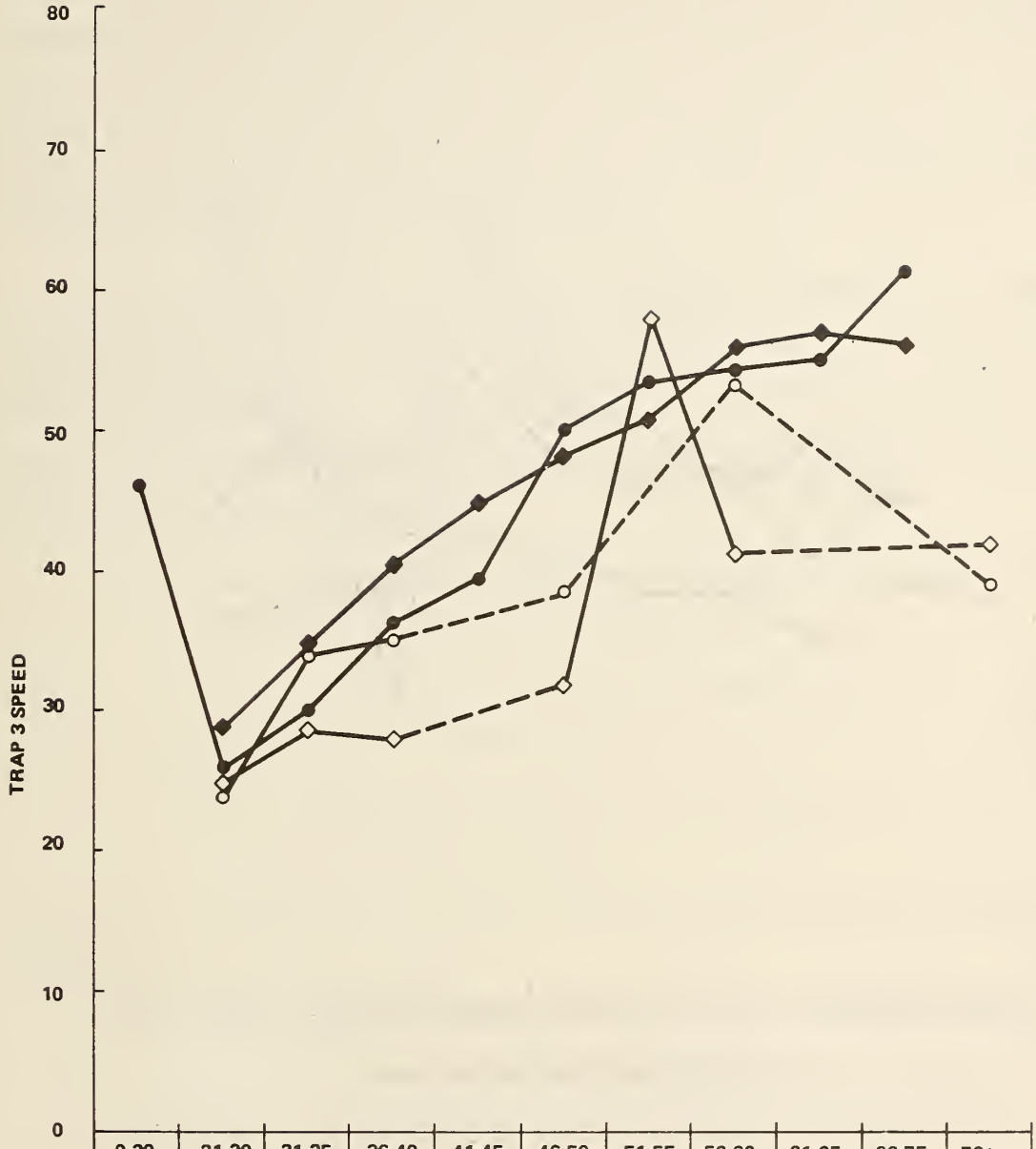


FIGURE C-11
MEAN TRAP 2 SPEEDS (NIGHT)



0-20	21-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-75	76+
INITIAL SPEED SAMPLE SIZES										
0	10	4	7	31	13	10	11	5	4	0
0	1	2	4	0	1	1	2	0	0	1
1	6	4	2	6	1	4	5	3	4	0
0	2	1	2	0	2	0	2	0	0	1

FIGURE C-12
MEAN SPEED CHANGE BETWEEN TRAP 1 AND TRAP 2 (NIGHT)

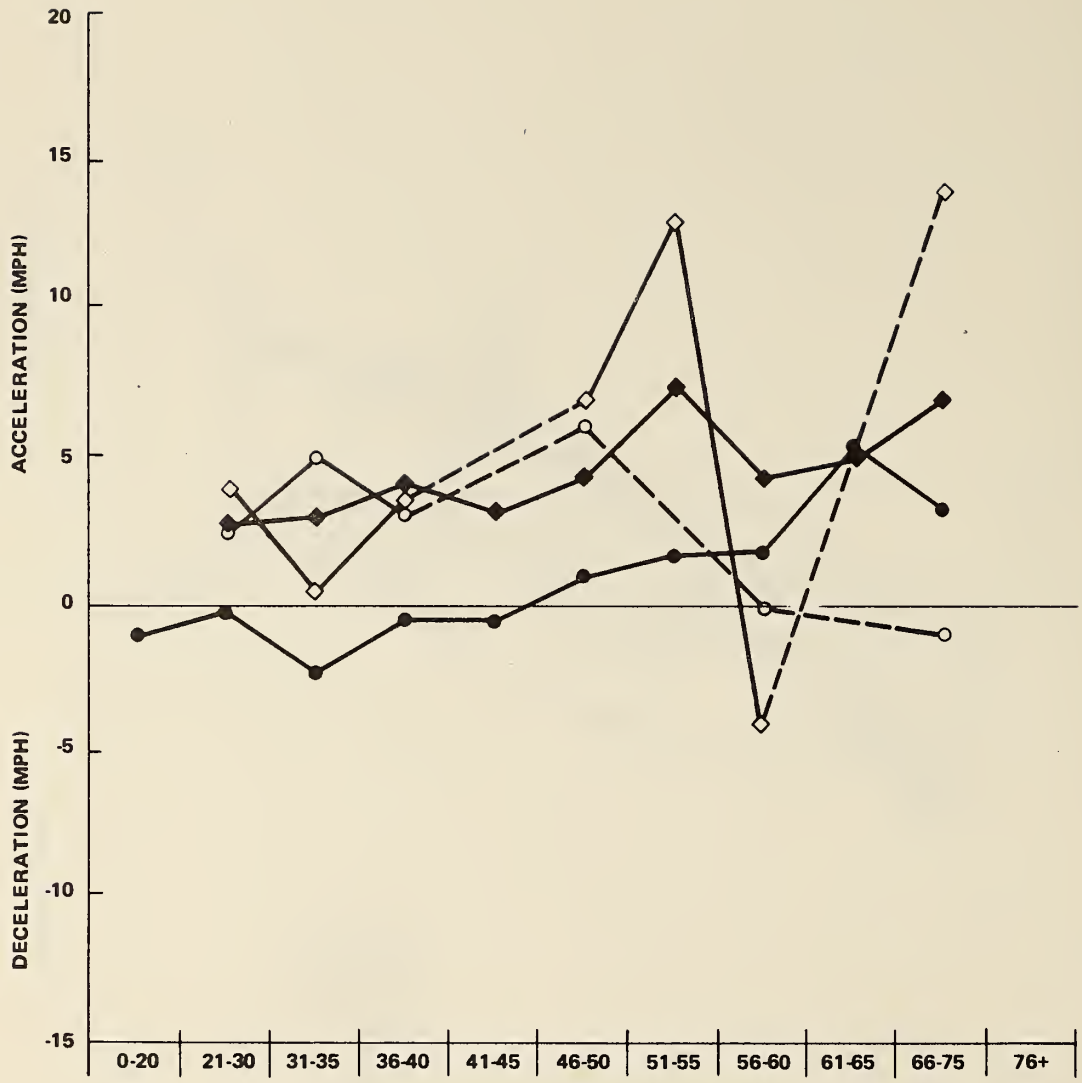


●	0	10	4	7	31	13	10	11	5	4	0
◆	0	1	2	4	0	1	1	2	0	0	1
○	1	6	4	2	6	1	4	5	3	4	0
◇	0	2	1	2	0	2	0	2	0	0	1

NUMBER OF OBSERVATIONS BY CATEGORY

● 1974 TRUCK SPEED
◆ 1974 CAR SPEED
○ 1975 TRUCK SPEED
◇ 1975 CAR SPEED

FIGURE C-13
MEAN TRAP 3 SPEEDS (NIGHT)



●	0	10	4	7	31	13	10	11	5	4	0
◆	0	1	2	4	0	1	1	2	0	0	1
○	1	6	4	2	6	1	4	5	3	4	0
◇	0	2	1	2	0	2	0	2	0	0	1

NUMBER OF OBSERVATIONS BY CATEGORY

● 1974 TRUCK SPEED
◆ 1974 CAR SPEED
○ 1975 TRUCK SPEED
◇ 1975 CAR SPEED

FIGURE C-14
MEAN SPEED CHANGE BETWEEN TRAP 2 AND TRAP 3

higher mean accelerations between Traps 2 and 3 under the sign warning conditions. Slow speed trucks seem to be relatively unaffected by the signs in terms of Trap 2 speeds with increasing impact being seen as the initial speed classification increases. The increasing impact on Trap 2 speeds as the speed of the approach vehicle increases is a desirable result of any warning sign test.

In summary it may be said that the motorist warning sign test did produce some significant increases in deceleration as approach vehicles apparently heeded the warning sign pair on the north side of the Prosser Creek Bridge. This conclusion can be made in spite of a small data sample. Relative to statistically significant results it may be concluded that the sign produced:

- Increased deceleration of cars in the daytime for the 31-60 mph categories
- Increased deceleration of high speed, 61-75 mph, trucks during the day
- Increased deceleration of nighttime cars in the 36-40 mph category.

Although the sample size was insufficient for statistical testing, it is fairly clear that:

- 1975 car decelerations in approaching the bridge under the sign experiment were larger than corresponding 1974 base data for nearly all speed categories, both day and night.
- The truck speed deceleration increases due to the signs were similar to that in cars, however, truck behavior is slightly different than cars, particularly in their Trap #2/Trap #3 comparisons.

- Based upon the data presented and the observer's comments it is likely that minimal approach speeds to the bridge were lowered by the sign and the distributional distance from the bridge of the minimal speed location was likely shifted closer to the bridge.

One of the most interesting results of the analysis is conjectured on the basis of Figure C-6. It appears that within the 30-75+ mph approach speeds there is almost a universal constant deceleration by vehicle type during daytime where the signs produced an increase in the value of the constant. On the other hand the corresponding nighttime data of Figure C-12 seems to reveal a slightly increasing deceleration as a function of increased initial speeds.

REFERENCES

1. Hanscom, Fred R., Driver Awareness of Highway Sites With High Skid Accident Potential, Bio Technology, Inc., 31 July 1974.

2. Manual on Uniform Traffic Control Devices, DOT/FHWA, 1971.

3. Highway Design Manual of Instructions, California Department of Transportation, Division of Highways.

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